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‘An Investigation of Kicking Kinematics in Female Rugby Players’

This thesis is submitted to fulfil the requirement of a Masters in Research to the University of Dublin, Trinity College

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DECLARATION

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Molly Eve Boyne, BSc (Physiotherapy)

SUMMARY

Women's rugby is one of the fastest growing sports in the world (World Rugby, 2017). Despite this, there is a dearth of research into this sport, and how it compares to men's rugby. Rugby laws are the same for both sexes, however, there are differences in the men's and women's games. As well as physical and biomechanical differences, there is variation in technique, experience, and coaching between men and women. This manifests itself in many aspects of the game, one such being the area of kicking. An important skill in the modern game (Quarrie & Hopkins, 2015), kicking is widely perceived as poor in women's rugby (Rowan, 2019), yet, no research has been carried out to verify this. The lack of understanding of kicking in the women's game may limit female athletes' ability to achieve peak performance and place them at greater risk of injury by assuming they kick using the same technique as men.

This project aimed to bridge the gap in the literature by investigating kicking in female rugby players. As a first step, a systematic review and meta-analysis comparing kicking biomechanics in male and female athletes in field-based sports was carried out. The purpose of this review was to provide the research team with insight into research already carried out in this area, and to inform the methodology for our own investigation. The results of this study highlighted the dearth of research in women's kicking sports, as only soccer could be included in the review. Differences in soccer kicking biomechanics between the sexes included greater ball velocities, distal lower limb velocities, hip and knee torques, and ankle plantarflexion angles at ball strike in men, while women exhibited greater trunk flexion.

Armed with this learning, the research team developed a study protocol which aimed to investigate the kicking kinematics and hip and groin health of female rugby players, compared to their male counterparts. Participants were to be recruited from the men's and women's teams playing in the highest domestic rugby leagues in Ireland and testing was to be carried out in the Irish Rugby Football Union (IRFU) High Performance Centre (HPC). The assessment battery

consisted of a clinical hip and groin examination and a two-dimensional analysis of kicking. We had completed pilot testing and were about to commence recruitment when the Covid-19 pandemic was declared in March 2020. As a result of the ensuing global health crisis, this project was subject to significant delays and challenges. The original protocol and its objectives were adapted many times in an effort to ensure testing could be carried out in a safe, feasible manner. A total of four main iterations were developed during the course of the project.

The final protocol was implemented in May 2021. A day of testing was carried out in the IRFU HPC with elite female kickers involved in the Ireland XVs and 7s teams. Only female athletes were assessed due to strict IRFU guidance on the maintenance of infection prevention control pods and the prior competitive commitments of the men's teams. A total of nine players were recruited and asked to perform place and drop kicks on goal on the HPC indoor pitch. Kicking kinematics were recorded using a high-speed camera and three electrogoniometers attached to the hip, knee, and ankle of the kicking leg. Analysis of the electrogoniometer results revealed significant distortion to the data, indicating that these devices were not robust enough to manage the dynamic nature of kicking. Pose estimation software and a manual protractor method were used to validate the results. During place kicks, a mean maximal hip extension angle of -26.25 ± 18.31°, knee flexion angle of 102.73 ± 1.66°, and hip flexion angle of 110 ± 22.92° were used by female rugby players. Drop kicks were performed with a mean maximum knee flexion angle of 105.91 ± 12.86° and a maximal hip flexion angle of 91.48 ± 26.2°.

While this project had a number of limitations, I am confident that significant learning can be gained from the process. The original protocol developed to explore hip and groin health and kicking biomechanics in female rugby players compared to their male counterparts is robust. Undertaking this procedure using inertial sensors to record kicking biomechanics would provide pioneering insight into kicking in women's rugby. Greater understanding of this skill and the sport as a whole is needed to ensure its safe and sustainable growth for many years to come; I believe this study is the first step on this journey.

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Reflecting on the past two years is a humbling process. There have been countless challenges along the way, which could not have been overcome without the support of my family, friends, and colleagues, and many victories that would not have been as special without them by my side. I am truly grateful to be surrounded by the very best people whose impact on my life and my work cannot be overstated. I would like to thank them sincerely for their contribution, both directly and indirectly, to this thesis.

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encouragement, and patience, especially in the last few months. I would not be who I am today without you, and you mean the world to me.

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Thank you for always reminding me that we can do hard things. And guess what? We did.

I love you to the moon and back.

ABSTRACT

Title: An investigation of kicking kinematics in female rugby players

Author: Molly Eve Boyne

Background: Women's rugby is one of the fastest growing sports in the world. Yet, there is a dearth of research in the game and how it compares to men's rugby. Anecdotal evidence indicates that female players do not follow the same development pathway as their male counterparts; as a result, differences between the sexes include variation in playing experience and skill acquisition. One such skill is that of kicking. No published research has been carried out exploring the biomechanics of this skill in female rugby players; this project aimed to fill this gap in the literature.

Methods: A systematic review and meta-analysis comparing kicking biomechanics in male and female athletes in field-based sports was carried out by the research team to inform our own study. A testing protocol was designed to evaluate hip and groin health and kicking kinematics in female rugby kickers, as compared to their male counterparts. With the onset of the Covid-19 pandemic, significant amendments to the original testing procedure were required. Official testing took place with elite female athletes in the IRFU High Performance Centre. Kicking biomechanics for place and drop kicks were recorded using a high speed camera and three electrogoniometers.

Results: Male soccer players produced greater ball velocities, distal lower limb velocities, and ankle plantarflexion angles at ball strike than females, as per the systematic review. For our own study, nine Ireland Women's XVs and 7s rugby players were recruited. Significant electrogoniometer data errors were reported, indicating that these devices are not suitable for dynamic field-based testing. Place kicks were performed with a mean maximal hip extension angle of -26.25 ± 18.31°, knee flexion of 102.73 ± 1.66°, and hip flexion of 110 ± 22.92°. Drop kicks were carried out with a mean maximum knee flexion angle of 105.91 ± 12.86° and a maximal hip flexion angle of 91.48 ± 26.2°.

Conclusion: Biomechanical differences exist between male and female soccer players when performing kicks. It remains unknown whether the same is true in rugby. A piloted protocol to investigate this was developed as part of our project. This could be used effectively by future researchers to begin characterising kicking in women's rugby.

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LIST OF ABBREVIATIONS

7s	Rugby Sevens
XVs/15s	Rugby Union Fifteens
X	Rugby Tens
2D	Two Dimensional
3D	Three Dimensional
4G	Fourth Generation Synthetic Turf
AFL	Australian Football League
AIL	All Ireland League
ANOVA	Analysis of Variance
ASIS	Anterior Superior Iliac Spine
CD ROM	Compact Disc Read-Only Memory
CIs	Confidence Intervals
CMcH	Clíodhna McHugh
CS	Ciaran Simms
DCU	Dublin City University
DPIA	Data Protection Impact Assessment
DPO	Data Protection Officer
ECS	Energia Community Series
FIFA	Fédération Internationale de Football Association
FW	Fiona Wilson
GAA	Gaelic Athletic Association
GDPR	General Data Protection Regulations
HAG	Hip and Groin
HAGOS	Hip and Groin Outcome Score Questionnaire
HPC	High Performance Centre
Hz	Hertz
IRFU	Irish Rugby Football Union
JM	Joanne Montgomery
JW	Julia Wall
LED	Light Emitting Diode
LL	Leinster League

MB	Molly Boyne
MD	Mean Difference
N/A	Not Applicable
NVD	Nicol Van Dyk
PCR	Polymerase Chain Reaction
PIL	Patient Information Leaflet
PPE	Personal Protective Equipment
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
RFC	Rugby Football Club
RN	Ross Norman
ROM	Read-Only Memory
SD	Secure Digital
U12s	Under 12s
U18s	Under 18s
U20s	Under 20s
UCC	University College Cork
US	United States of America
WRWC	Women's Rugby World Cup

CHAPTER 1:

INTRODUCTION

1.1 Rugby Overview

Rugby Football is a team contact sport played across the world under several guises. Thought to have originated in England in the mid-1800s, it is now played in 124 countries across six continents (World Rugby, 2020). As the popularity of rugby has increased, different formats of the sport have emerged and developed. These include Rugby Union (XVs), Rugby League, Rugby Sevens (7s), Rugby Tens (X), Touch Rugby and Tag Rugby. The game is played on a pitch measuring 100 metres long and 70 metres wide (Figure 1), with goal posts located at either end. Each goal post is comprised of two tall vertical posts, 5.6 metres apart, joined by a cross bar three metres from the ground (Figure 2). Rugby involves two teams of 15, 10, or seven players competing to score more points than the opposition and win the game (World Rugby, 2021). This is achieved through scoring a try by touching the ball down beyond the opposite team's goal line or kicking the ball between the posts using a place or drop kick. A try is worth five points to the scoring team, with two further points available if the team's kicker successfully kicks a conversion. Penalty kicks and drop goals are worth three points each. Rugby Union (XVs) is the most commonly played form of rugby, with over 9.6 million players worldwide (World Rugby, 2020). It is both an amateur and professional sport, with players of all ages and standards participating in the game. Each team competes with 15 players (eight forwards and seven backs), with matches lasting 80 minutes. Rugby 7s is a higher paced version of the game, with seven players on each side competing on a full-sized pitch for a total of 14 minutes.

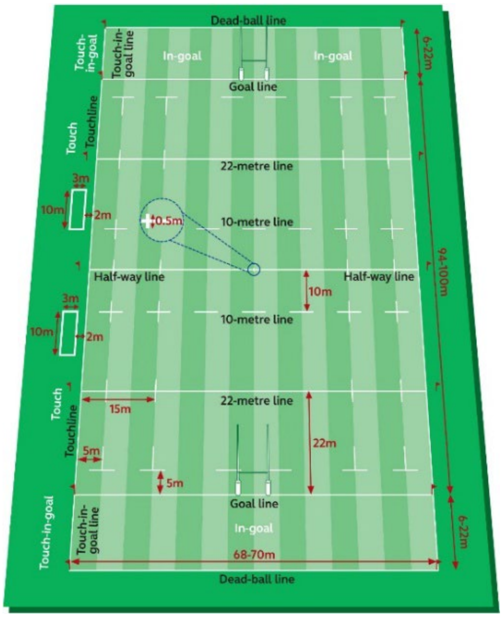

Figure 1. Rugby pitch dimensions (World Rugby, 2021)

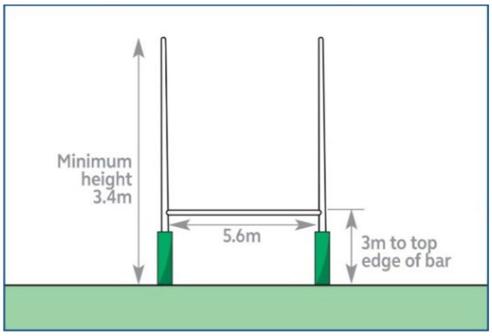

Figure 2. Rugby goalpost dimensions (World Rugby, 2021)

1.2 Kicking in Rugby

1.2.1 Types of Kicks

Participation in all forms of rugby requires players to be proficient at a wide variety of skills, including passing, kicking, catching, tackling, and evasion (Chiwaridzo et al., 2019). An athlete's ability to perform these skills efficiently under both pressure and fatigue constraints affects the success of their team (den Hollander, Brown, Lambert, Treu, & Hendricks, 2016; Hendricks et al., 2018). Kicking plays an important role in rugby as it can directly influence the outcome of matches

(Quarrie & Hopkins, 2015). There are three main types of kick: place, drop, and punt kick, of which the former two are used to score points (Padulo, Granatelli, Ruscello, & Dottavio, 2013). Place kicks are performed by kicking a static ball that has been positioned on the ground or on a kicking tee (World Rugby, 2021). This type of kick is used in Rugby Union to kick conversions after a try or to score three points in the event of a penalty. Drop kicks are a more dynamic style of kick that are achieved when the athlete drops the ball to the ground and kicks it as it rises from its first bounce (World Rugby, 2021). Drop kicks are used in Rugby Union and Rugby 7s for restarts and drop goals, and in Rugby 7s for conversions.

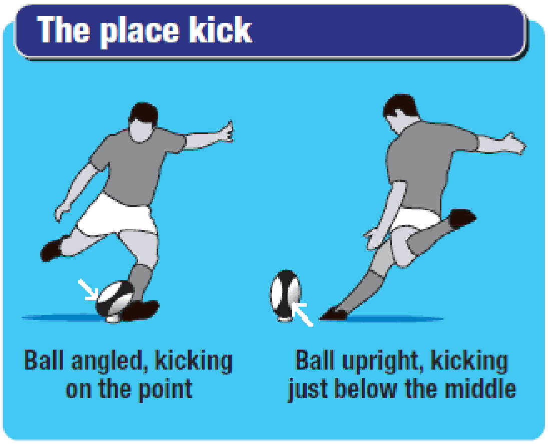

Figure 3. Rugby place kick technique. Source: https://www.rugbycoachweekly.net/rugby-drills-and-skills/kicking-catching/rugby-coaching-session-for-the-place-kick/

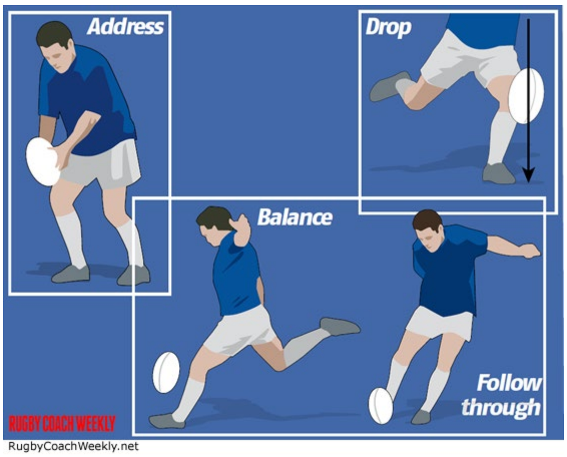

Figure 4. Rugby drop kick technique. Source: https://www.rugbycoachweekly.net/rugby-drills-and-skills/kicking-catching/drop-kick-four-steps-getting-match-off-perfect-start/

1.2.2 Research Interest

Kicking influences the success of teams in rugby, with 45% of total points in international matches coming from place kicks (Quarrie & Hopkins, 2015). The ability to produce high velocity, accurate shots on target is a valuable asset to any team. Understanding the mechanism by which athletes produce optimal kicks and how this can be replicated is therefore an area of priority for many rugby stakeholders. Players and coaches alike are interested in improving kicking techniques in order to enhance individual and team performances. Researchers and clinical professionals are invested in this subject in terms of skill analysis, developments, and injury prevention. Prior to the last decade, there were very few studies investigating the biomechanics of this skill in rugby, particularly given the extent of kicking research in soccer. The biomechanics of rugby place kicking can be compared to that of a soccer instep kick; however, a number of differences exist. The oval shape of the rugby ball influences a number of aspects of the kick including its flight trajectory and positioning before the kick i.e., on a tee (Sinclair et al., 2017). Place kicks are taken using a static ball, while instep kicks can be performed on a static or dynamic ball. The target of these kick types is also different; shooting into a soccer net requires a different ball trajectory to kicking over the rugby cross bar. Given these variations, it would be inappropriate to solely rely on soccer kicking research to evaluate rugby biomechanics (Hébert-Losier, Lamb, & Beaven, 2020). Thankfully, the breadth of research into place kicking in rugby has expanded significantly in recent years, with a number of researchers having taken a keen interest in this topic (Atack, 2016; Bezodis, Trewartha, Wilson, & Irwin, 2007; Sinclair, Taylor, et al., 2014). This has facilitated better understanding of the skill itself and the mechanisms underpinning it. However, there remains a gap in the literature in relation to drop kicking.

1.2.3 Phases of Place Kicking

1.2.3.1 Preparation

Place kicking is a self-paced skill (Jackson, 2003). This means that rugby kickers have time to plan and consider their performance while the ball remains motionless, rather than being influenced to make decisions under time pressure. During this time, elite athletes use cognitive behavioural skills to prepare for their strike (Cohn, 1990). In rugby place kicks, this takes the form of a pre-performance routine. Athletes prime themselves for their task by completing a number of systematic actions and thoughts (Singer, 2000), with concentration time increasing with the distance and acuteness of the impending kick (Jackson, 2003).

Once the pre-kick routine has been completed, the rugby place kick takes place. Performance of this skill is characterised by four phases: the approach, the kicking phase, the ball contact phase, and the follow-through phase (Figure 5).

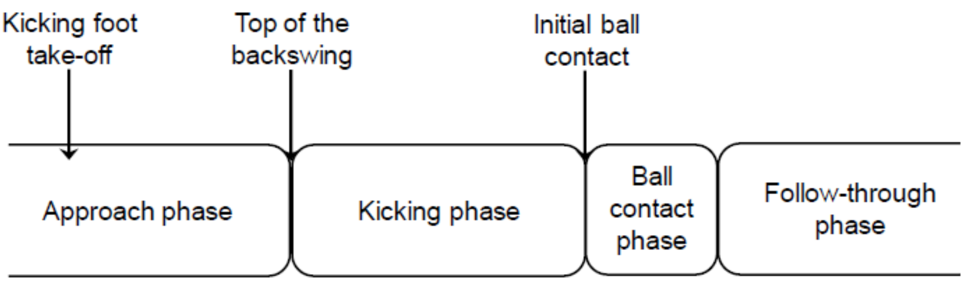

Figure 5. Phases of a rugby place kick (Atack, 2016)

1.2.3.2 Approach Phase

This phase begins when the player makes their first movement towards the ball. From their pre-routine position, athletes usually take a number of steps to the ball from angle. This is anecdotally described by coaches as 45° towards the target (Greenwood, 2003; Wilkinson, 2005). However research suggests that 30° is the optimum approach angle for attaining maximum distance during a rugby place (Linthorne & Stokes, 2014). The speed at which players approach the ball varies based on accuracy constraints; slower approaches are used when athletes are required to make a shot on target (Adrian Lees & Nolan, 2002). Given the necessity of both velocity and accuracy in rugby place kicks, approach velocity may play an important role in the performance of this skill (Atack, Trewartha, & Bezodis, 2019).

Research in soccer and Australian Rules football have found that the length of the last step to the ball influences its velocity (K. Ball, 2008; Shan, Yuan, Hao, Gu, & Zhang, 2012). In rugby, those with a longer last step performed more accurate place kicks than those who use a shorter final step (Atack, 2016). A longer step facilitates greater hip extension and knee flexion, exploiting the stretch-shortening cycle; the greater the muscular stretch, the greater the potential energy generation and resultant release (Atack, 2016; Shan & Westerhoff, 2005). Approach angle also influences the degree of trunk and pelvis rotation that occurs during kicks. The more obtuse the angle, the more rotation required to kick the ball towards the goal posts. A significant stretch is applied to the abdominals which, when combined with hip extension, knee flexion, and opposite arm abduction, creates a 'tension arc' (Shan & Westerhoff, 2005). This technique has a positive outcome for maximal kick velocities, however, the introduction of greater rotational forces may have a less favourable impact on ball trajectory, and consequently, kicking success (Atack et al., 2019). The phase ends when the kicking foot reaches the top of the backswing.

1.2.3.3 Kicking and Ball Contact Phases

The end of the approach phase signals the start of the kicking phase (Atack, 2016). The swinging motion of the kick is characterised by a proximal-to-distal segmental pattern of movement (Putnam, 1993). This concept has been explored extensively in soccer, with some research identifying the technique in rugby kicks (Aitchison & Lees, 1983; Atack, 2016). The sequence of movement of the kicking leg begins with pelvic rotation, followed by hip flexion, knee extension, and ankle dorsiflexion (Atack, Trewartha, & Bezodis, 2014). The initiation of motion by the proximal segments is underpinned by the summation of speed principle (Bunn, 1972): movement starts at the proximal segments and progresses sequentially down to the extremities. Speed of the segments increases as it moves down the kinetic chain, with the velocity of the distal end of the limb being a product of the summation of all the previous individual segments (Putnam, 1993). As a result, hip velocity plays a key role in producing high foot velocity. Knee extension angular velocity at ball contact is also significant, as it is the most important factor in determining resultant ball velocity (Sinclair, Taylor, et al., 2014).

The proximal-to-distal sequence begins at the kicking leg hip, which is extended until immediately before the support leg foot makes contact with the ground (Atack et al., 2014). A hip flexor moment is initiated, causing the joint to move into flexion. Hip flexion angular velocity is highest at the beginning of the swing (Sinclair, Taylor, et al., 2014), building energy through the kicking phase. The kicking leg knee is flexed until halfway through the kicking phase, at which point, it extends. Hip flexion velocity decreases as knee extension velocity increases (Sinclair et al., 2017). The knee continues to extend until it hits maximal velocity just before ball strike (Atack et al., 2014) This energy then transfers to the foot, which reaches its maximum velocity at the point of ball contact (Dörge, Andersen, SØrensen, & Simonsen, 2002). The speed of the distal lower limb at this point directly impacts ball velocity (De Witt & Hinrichs, 2012). This proximal-to-distal sequence is important in ensuring that energy is transferred down the leg efficiently in order to produce high quality kicks.

A successful place kick requires a high velocity, accurate strike to ensure that the ball will travel the distance from the tee and pass between the posts (Atack et al., 2019). However, research has suggested that there is a trade-off between speed and accuracy in rugby place kicking (Atack, Trewartha, & Bezodis, 2017; Atack et al., 2019; Sinclair et al., 2017). Peak hip flexion angular velocity, knee extension angular velocity at ball contact, and foot linear velocity are greater in rugby place kicks when the aim is to achieve maximum velocity rather than accuracy (Sinclair et al., 2017). Ankle plantarflexion angles at ball contact are also greater during high-speed kicks, compared to kicks for accuracy, which present with a more dorsiflexed and externally rotated ankle. The former mimics an instep kick which is used to produce high velocity shots in soccer (Asami & Nolte, 1983; Kellis & Katis, 2007), while the latter reflects a side foot kicking style, commonly used by soccer players to improve accuracy (Levanon & Dapena, 1998). Athletes kicking for distance exhibit larger thorax-pelvis angles, as well as a hip dominant technique, with greater positive work at the hip and less at the knee. This is indicative of the development of a tension arc, as the rotation applies a greater stretch across the torso. While the use of this technique may be beneficial in terms of increasing ball velocity in rugby, it can result in greater longitudinal ball spin and produce an inaccurate kick (Atack et al., 2019). Alternatively, a knee dominant technique is associated with greater accuracy (Atack et al., 2019). (Hébert-Losier et al., 2020) suggest that there are seven biomechanical variables that determine the success of a place kick; these are controlling the body's centre of mass speed at the point of ball contact, maintaining this speed through the contact, using greater hip and knee flexion angles at ball strike, increasing knee flexion angles during the swing phase, and reducing the degree of trunk rotation away from the target during the swing.

1.2.3.4 Follow-through

The follow-through phase of the kick occurs after the ball has left the foot. It is characterised by an attempt by the kicker to dissipate some of their forward momentum. This may take the form of a run, hop or step after the strike to release the additional energy produced during the previous three kicking phases (Bezodis & Winter, 2014).

1.3 Women's Rugby

1.3.1 Development of the Game

Women's rugby is one of the fastest growing sports in the world, with rapid increases in participation in recent years. Women and girls now represent more than a quarter of the global playing population (World Rugby, 2020). To capitalise on this opportunity and continue to progress the women's game, World Rugby developed a plan to accelerate the global development of the sport over an eight year period (2017-2025)(World Rugby, 2017). This strategy aims to achieve equity for women in rugby, on and off the field, by doubling the number of registered players, producing quality high performance programmes and competitions, including women in its governance and management structures, promoting women in rugby at all levels, and driving development of the game with sustainable investment. In Ireland, there has been a similar surge in participation in recent years (Lunn & Kelly, 2019). The success of the Ireland Women's XV team in the Women's Rugby World Cup (WRWC) 2013 and the subsequent hosting of the event in Ireland in 2017 were watershed moments for the growth of the game in this country. The ever-increasing profile of the national XVs and 7s teams continue to drive the support for women's rugby to new levels. In 2017, there were 1,341 active adult players and 2,500 youth players involved in 190 teams (Irish Rugby Football Union, 2017). That year, the Irish Rugby Football Union (IRFU) announced its Women in Rugby Action Plan 2018-2023 to build on this momentum and create a strategic focus for the development of the women's game in Ireland (Irish Rugby Football Union, 2017). The aims of this plan reflect those of World Rugby (2017) by making rugby a sport of equal opportunity for all, increasing female participation across the game by 20%, and creating a performance system that supports the development of elite players and competitions.

1.3.2 Research in Women's Rugby

It is clear that there are high hopes for the development of women's rugby, both nationally and internationally. However, there remains a stark dearth of research into this sport. There are very few published studies characterising different aspects of the women's game and how it compares to men's rugby. Rugby laws are the same for both sexes (World Rugby, 2021); however, there are differences in the men's and women's games, which are determined by sex. As well as the anthropometric, physiological, and biomechanical variation between sexes (O. Heyward, Nicholson, Emmonds, Roe, & Jones, 2020; Mascherini, Castizo-Olier, Irurtia, Petri, & Galanti, 2018a; Nieves et al., 2005; Schorr et al., 2018), there are also differences in speed, strength, power, and endurance (S. Ball, Halaki, & Orr, 2019; Miller, MacDougall, Tarnopolsky, & Sale, 1993; Pyne, Higham, Clarke, Mitchell, & Eddy, 2012). These may be compounded by variation in technical skill, experience, coaching, and playing style between men and women (Joncheray & Tlili, 2013; Waterman, 2019); however, due to limited research, this can only be anecdotally described.

1.3.3 Kicking in Women's Rugby

One aspect of women's rugby that receives considerable attention is that of kicking. This fundamental skill is a key method of scoring points in rugby, as well as relieving pressure, gaining territory, and challenging the opposition. Despite the diverse utility of this skill, kicking in women's rugby is widely perceived as poor (Rowan, 2019). The women's game is described as having a more free flowing, running style, with less tactical and point-scoring kicks than its male equivalent (Rowan, 2019). This is anecdotally attributed to the preconception that the ability of female kickers lags behind that of men, resulting in poor technical performance when striking the ball (Waterman, 2019). The causes of this disparity cannot be definitively stated, due to the distinct lack of research into kicking in women's rugby. However, kicking kinematics have been studied at length in soccer, including comparison of male and female biomechanics and outcomes. This research indicates physical differences between men and women (Shan, 2009) may play a significant contributing role. These result in differences in soccer kicking biomechanics (Katis, Kellis, & Lees, 2015), such as slower ball speed (Shan, 2009) and joint velocity (Barfield, Kirkendall, & Yu, 2002) in female kickers. Variation in muscle activation during kicks (R. H. Brophy et al., 2010) may predispose female kickers to different injuries to their male counterparts, but there is little research supporting this in rugby.

Other potential reasons for the difference between male and female kicking performance are coaching and experience. Many women join rugby later in life, while the majority of men are exposed to the game from a much younger age (Waterman, 2019). For new players, the fundamentals of catching, passing, and tackling are necessary to learn before taking to the field. As a result, specialised skills such as kicking are low priorities in terms of initial skill development. Players with previous experience in kicking sports tend to be chosen to carry out kicking duties, as limited kicking coaching is available to female athletes (Waterman, 2019). In comparison to male players who specialise as goal kickers from a young age and work with kicking specific coaches to hone their skills, female players rarely have the opportunity to work with kicking coaches. As such, those with previous kicking experience are often chosen as goal kickers, as they have the basic movement patterns required to perform this role competently. The lack of training and emphasis on this facet of the game has likely contributed to poor performance in the women's game.

1.4 Hip and Groin Health

Injuries to the hip and groin (HAG) are common in field based sports, due to their multidirectional nature (Julianne Ryan, DeBurca, & Mc Creesh, 2014). Players are required to anticipate and adapt to constant changes in pace and direction, while managing axial and rotational loads of up to 12 times their body weight during matches (Giza, Mithöfer, Matthews, & Vrahas, 2004). In the football codes of soccer, AFL, and rugby, kicking increases the demands placed on the athletic hip and groin (Chahla, Sherman, Philippon, & Gerhardt, 2019). As a result, hip and groin injuries are common in kicking sports such as rugby(J Ryan, McCreesh, & DeBurca, 2014) and soccer (Langhout et al., 2019). The prevalence of hip and groin injuries is high in men's rugby and is among the six most cited injuries in the sport (Brooks & Kemp, 2008). Incidence of hip and groin injuries has been reported as 21% among academy rugby players (J Ryan et al., 2014). When looking specifically at kicking-related injuries, incidence during matches was 0.7/1000 player-match hours (Lazarczuk et al., 2020). This increased significantly for players who carry out the majority of kicking duties. Fly-halves had the greatest proportion of kicking injuries (47%) with an incidence of 4.6 injuries/1000 match hours (Lazarczuk et al., 2020).

It is clear that hip and groin injuries are common in men's rugby; however, little is known about the prevalence of this type of injury in female players. A systematic review of injuries in women's rugby did not refer to HAG pathology as a frequent injury in this cohort (King et al., 2019). Research by Kerr et al. (2008) found that collegiate women's rugby athletes had a similar rate of pelvis, hip, and groin injuries compared to their male counterparts. Given that such injuries are common in women's soccer and other kicking sports (Chahla et al., 2019; Langhout et al., 2019; Ralston et al., 2020), the dearth of investigation into hip and groin health in female rugby players may be an indicator of the lack of kicking involved in the women's game. In addition, the differences in rugby playing age, kicking experience, and specialised coaching may result in variation in injury patterns between the sexes. Overall, the impact of hip and groin injury on the women's game and its association with kicking remains unknown.

1.5 Thesis Outline

It is clear that there is a large gap in the literature regarding the biomechanics of kicking in women's rugby. The kinematics and kinetics of this skill have been well explored for both sexes in soccer. In recent years, increasing attention has been paid to kicking performance in men's rugby, given its influence in match outcomes. The dearth of research with female rugby kickers offers a unique opportunity to conduct pioneering investigations. As women's rugby continues to grow internationally, a greater understanding of the fundamental skills and their implications for injury is needed. Female-specific research would be valuable to players, coaches, and management for the planning and development of targeted training, athletic development, and injury prevention strategies. This would create an evidence-based platform from which safe, sustainable growth of women's rugby can occur and foster a culture of equality for female players at all levels.

In order to begin bridging this gap in the literature, the overall aim of this project was to investigate the kinematics of kicking. The research team's objectives and methods of achieving this were adapted many times during the course of the research due to unforeseen circumstances. These challenges resulted in the development of number of study protocols, each with slightly different anticipated outcomes. Chapter 3 details the varying goals and procedures for these iterations. Broadly, the objectives for this project were to:

1. Synthesise the available evidence comparing the biomechanics of kicking in male and female kickers in field based sports by performing a systematic review and meta-analysis of the current research

2. Develop a protocol to investigate kicking biomechanics and hip and groin health in female rugby players, based on the findings of this review and previous research carried out with male athletes
3. Implement the aforementioned protocol to explore the kinematics of kicking in female rugby players, as compared to their male counterparts
4. Where possible, begin to identify the key characteristics of kicking in women's rugby players.

This thesis will outline the background to this study, the creation of our first protocol and its development over time, the challenges we faced during the process, the emerging and amended iterations of the protocol, the results of pilot testing, and our subsequent learnings and recommendations for future research.

CHAPTER 2:

IT'S NOT ALL ABOUT POWER: A SYSTEMATIC REVIEW AND META-ANALYSIS COMPARING SEX-BASED DIFFERENCES IN KICKING BIOMECHANICS IN SOCCER

2.1 Background

A systematic review of current literature exploring kicking biomechanics in male and female athletes in field-based sports was performed. This was designed to inform the research team on the breadth of previous research in this area, provide an understanding of the knowledge base on this subject, inform on the need for future research, and guide the processes by which this could be achieved.

This systematic review, entitled, "It's not all about power: a systematic review and meta-analysis comparing sex-based differences in kicking biomechanics in soccer", has a number of peer-reviewed accreditations:

- Oral presentation, Women in Sport and Exercise Conference 2021, University of Worcester, 19th – 22nd April 2021 (Appendix 1)
- Poster presentation, the Female Athlete Conference 2021, Boston Children's Hospital, 10th – 12th June (Appendix 2)
- Accepted for publication in Sports Biomechanics, the journal of the International Society of Biomechanics in Sport, September 2021.

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2.2 Abstract

Kicking is fundamental in many field-based sports. Most studies investigating kicking performance have been conducted with male athletes, resulting in a dearth of specific data to inform coaching of this skill in female players. This systematic review aimed to compare kicking biomechanics in male and female athletes in field-based sports. As per PRISMA guidelines, articles were retrieved from searches across five online databases. Studies investigating kicking biomechanics in field-based athletes of both sexes were eligible for inclusion. Articles were screened using Covidence and data extracted based on STROBE recommendations. The review included 23 studies, featuring 455 soccer players. Male athletes produced significantly greater ball velocities and linear velocities of the ankle, foot, and toe than females. Males had greater ankle plantarflexion angles than females at ball strike, while females used larger trunk flexion ranges than males. Hip and knee torques and ball-to-foot velocity ratios were greater in men than women. Skilled players generated power using tension arcs; a technique not seen in novices. Skill level within sex may have a greater influence on kicking performance than differences between the sexes. This review highlights the need for further research investigating kicking performance in both sexes across the spectrum of sports.

Key words: kicking, biomechanics, kinematics, soccer, female athletes, systematic review

2.3 Introduction

Kicking is a fundamental skill in many field-based sports, including Australian rules football, Gaelic football, rugby, and soccer (Kevin Ball & Horgan, 2013; Blair, Robertson, Duthie, & Ball, 2020; A. Lees, Asai, Andersen, Nunome, & Sterzing, 2010; Quarrie & Hopkins, 2015). A variety of kicking techniques can be used in offensive and defensive scenarios for the purposes of passing, possession, and scoring (Peacock & Ball, 2019; Sterzing, 2010). Instep kicks, performed by striking the ball with the instep portion of the foot, are used predominantly to produce high ball speeds, while inside kicks, using the medial aspect of the foot, facilitate greater precision for passing (Levanon & Dapena, 1998). Players are required to be proficient across the range of kicking styles in order to manage the demands of specific game scenarios (Blair, Duthie, Robertson, & Ball, 2017).

The kinematic sequencing of a kick is divided into five phases: preparation, backswing, leg cocking, acceleration, and follow-through (R. Brophy, Backus, Pansy, Lyman, & Williams III, 2007). These are marked by six key events, namely kicking leg heel strike, toe-off, peak hip extension, peak knee flexion, ball strike, and toe velocity inflection (R. Brophy et al., 2007). Kicking success is dictated by the speed and accuracy of performance (Gheidi & Sadeghi, 2010; Rada et al., 2019). Efficient coordination, timing, and execution of these key events contribute to the quality and outcome of kicks (Langhout, Weber, Tak, & Lenssen, 2016).

Kick performance is an integral part of field-based sports as it influences match results (Quarrie & Hopkins, 2015; Robertson, Back, & Bartlett, 2016). A team's success is impacted by the kicking abilities of its players (Harrop & Nevill, 2014; Robertson et al., 2016) as athletes who perform accurate, high velocity kicks are more likely to score (Blair et al., 2017; Peacock & Ball, 2019). Understanding the mechanism by which athletes produce optimal kicks, as well as the factors that influence performance, such as skill level (Shan & Westerhoff, 2005) and kick type (Levanon & Dapena, 1998), are of interest to players and coaches alike. Researchers and clinical professionals are invested in this subject in terms of skill analysis, development, and injury prevention.

The majority of research investigating the biomechanics of kicking has been carried out on male athletes. Women's sport has grown exponentially in recent years, with record numbers of female players participating in games such as soccer (Fédération Internationale de Football Association, 2021), rugby (World Rugby, 2020), and Gaelic football (Ladies Gaelic Football Association, 2018). Despite this increase in playing population, there remains a dearth of research into the biomechanical and technical components of female sport. As a result, most coaching advice and injury prevention strategies provided to athletes of both sexes are based solely on data collected from male players (Sakamoto & Asai, 2013). This fails to account for the anthropometric and physical differences between males and females, such as those related to body composition (Mascherini, Castizo-Olier, Irurtia, Petri, & Galanti, 2018b), strength (V. H. Heyward, Johannes-Ellis, & Romer, 1986; Miller et al., 1993), range of motion, and flexibility (Allison et al., 2015). Training and experience influences players' kicking biomechanics (Shan & Westerhoff, 2005); thus, the lack of female-specific coaching methods may prevent female athletes from developing an optimal kicking technique and achieving peak performance. Employing unsuitable kicking methods may also place female kickers at greater risk of injury, by promoting biomechanically unfavourable movement patterns.

There is currently no review comparing kicking performance in both male and female athletes competing in field-based sports published in the scientific literature. While individual studies have examined differences in this skill between the sexes, a clear, synthesised comparison of biomechanical and technical elements of kicking in male and female athletes has yet to be defined. The aims of this systematic review are to 1) compare the kinematics and kinetics of kicking in male and female athletes in field-based sports, and 2) establish specific characteristics associated with kicking techniques in males and females.

2.4 Methods

2.4.1 Protocol and Registration

This systematic review was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) recommendations (www.prisma-statement.org) (Moher, Liberati, Tetzlaff, & Altman, 2009). The objectives, methodology, and inclusion criteria for this paper were established in a protocol, which was prospectively registered online with PROSPERO, an international database of systematic reviews (https://www.crd.york.ac.uk/prospero; registration number CRD42020154309).

2.4.2 Eligibility Criteria

Articles were deemed eligible for inclusion in this review based on criteria outlined in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Players participating in field-based kicking sports, including: - Rugby - Soccer - Football - Gaelic football - American football - Australian Rules football Outcomes investigated include biomechanical, kinematic, or kinetic elements of kicking. Feature and compare both male and female participants.	Non-primary research sources, including: - Reviews - Systematic reviews - Opinion pieces Full article text not available. Conference abstracts. Studies including fewer or equal to five participants. Involve kicking in a non-athletic environment. Examine kicking in non-field-based sports. Focus on mechanics of ball motion or flight. Investigate psychological aspects of kicking, such as cueing and learning effects. Contain a single sex of participants – male or female. Male and female participants not compared. Not available in the English language.

2.4.3 Information Sources

A comprehensive, systematic literature search was conducted with the assistance of a medical librarian. A search of electronic databases EMBASE, Medline (OVID), Web of Science, SCOPUS, and Engineering Village was conducted from their inception to April 2020. The last search was performed on 10th April 2020. This was supplemented by a grey literature search and a manual review of the reference lists of included studies.

2.4.4 Search Strategy

A broad search strategy was developed to ensure the thorough collection of all relevant studies from the aforesaid databases. No limitations were applied to the search with regards to the status or date of publication.

The key words included: leg movement, kick, kinematic, soccer, football, rugby, soccer player, football player. They were searched alone and in combination with MeSH terms (Appendix 3).

2.4.5 Study Selection

All articles retrieved with the search strategy were evaluated for inclusion eligibility using Covidence (www.covidence.org), a web-based software platform for primary screening of systematic reviews. Two reviewers (MB and FW) independently screened study titles and abstracts based on the inclusion and exclusion criteria (Table 1). Full texts for relevant articles were sourced and independently screened by the same reviewers (MB and FW). Any disagreement on the inclusion of studies was overcome through discussion between the reviewers until consensus was reached. The search methodology and screening process are detailed in Figure 6. Where multiple studies appeared to feature the same participant group, based on demographic data, they were described as one study, to prevent double reporting of results in this review (Appendix 4).

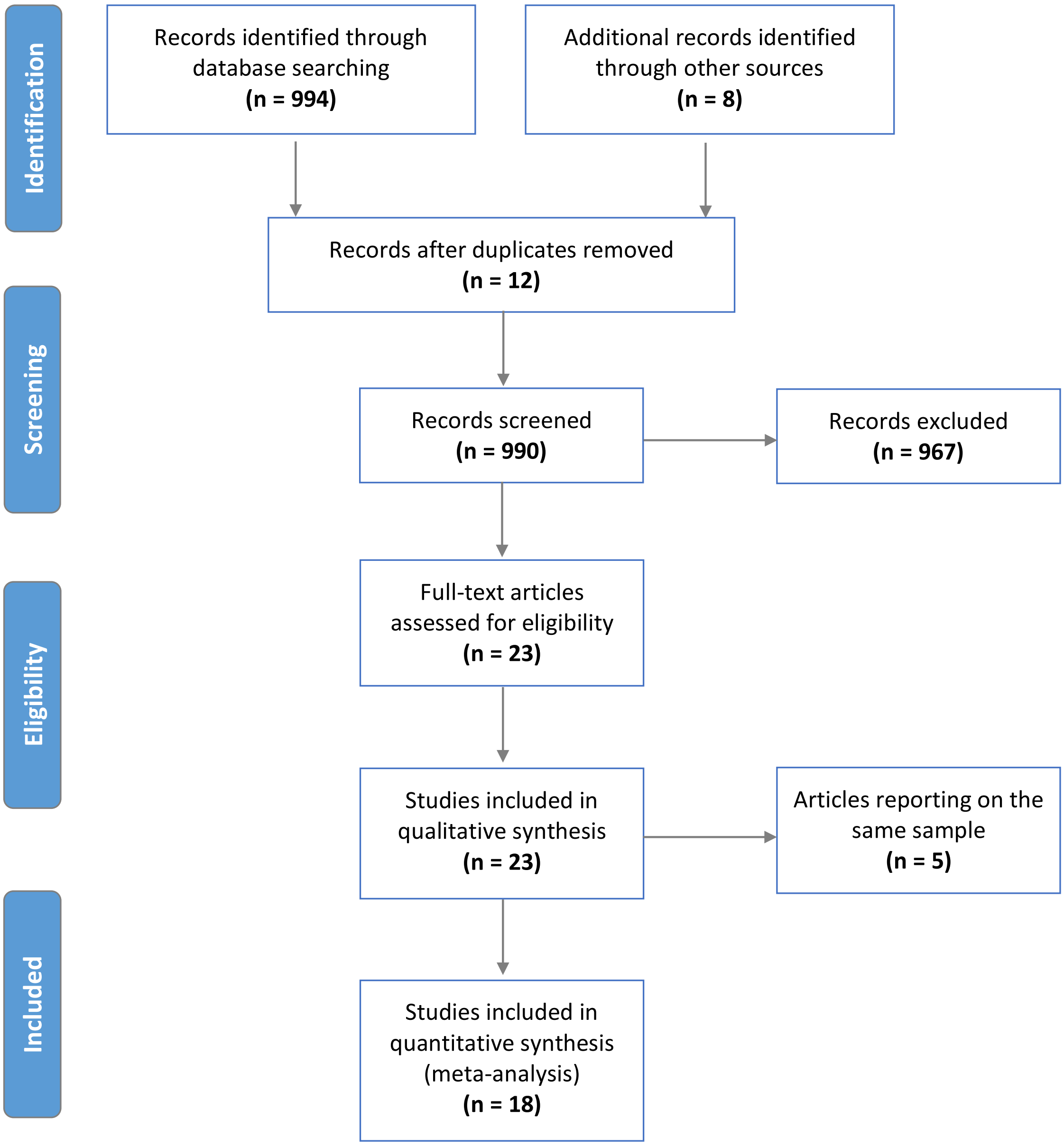


Figure 6: PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) flow diagram of studies screened for eligibility

2.4.6 Data Collection Process

When the screening and study selection process was completed, one reviewer (MB) extracted data from the included articles using the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines (von Elm et al., 2008). An evidence table was created, which included study aims and objectives, participant characteristics, data collection methods, testing procedures, outcome measures, and main findings. A second reviewer (CMcH) checked the gathered information. Any issues or queries were clarified through discussion.

2.4.7 Risk of Bias in Individual Studies

The methodological quality of the included studies was evaluated using the AXIS Tool for the Critical Appraisal of Cross-sectional Studies (Downes, Brennan, Williams, & Dean, 2016). This tool contains 20 questions, used to assess study design quality and risk of biases. Each question can be answered as "Yes", "No" or "Unsure/comment". A traffic light colour coding system was implemented to interpret the results of this tool, based on the method outlined by McHugh, Hind, Davey, and Wilson (2019). Green text indicated the finding had a positive impact on the quality of the study, red highlighted a negative influence, and amber was used to display an unknown effect of the outcome on the study's quality. The "unsure" amber response was assigned where there was a lack of clarity in the reporting of the subject in question. This assessment was performed independently by two reviewers (MB and JW). Where consensus could not be reached through discussion, a third reviewer was consulted (CMcH).

2.4.8 Data Analysis

A random-effects meta-analysis was conducted to compare the differences in ball velocities and joint linear velocities between male and female athletes across all included studies and to examine the overall effects. Group mean differences, 95% confidence intervals (CIs) and P-values were calculated using Review Manager (RevMan) software ([Computer program]. Version 5.4, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2020). The I^2 statistic was used to establish heterogeneity between studies (Higgins & Thompson, 2002). Low, moderate, and high levels of heterogeneity corresponded to I^2 values of 25%, 50%, and 75%, respectively. Sensitivity analysis was implemented in the incidence of substantial heterogeneity. Meta-analyses were not performed with other kinematic or kinetic variables collected as part of this review. The heterogeneity in reporting and lack of standardised definitions of these outcomes limited the authors' abilities to synthesis data using this analysis method. As such, the results for other biomechanical variables are presented descriptively.

2.5 Results

The results of the literature search and selection process are summarised in Figure 6. Following the removal of 12 duplicates, the database search strategy yielded 982 studies. Of these, 967 articles were excluded based on initial screening of titles and abstracts (Figure 6). The remaining 15 articles underwent full-text screening, and all were deemed eligible for inclusion. The reference lists of these papers were screened and yielded a further eight studies. Commonalities (Methods and Appendix 4) were accounted for, revealing a total of 18 studies comparing male and female kicking biomechanics in field-based kicking sports. Of these, five were conducted in the US, four were completed in Japan, two in Greece, Spain, and Canada, and one each in Iran, India, and Australia. Almost all (17/18 studies) focussed on kicking in soccer, with the remaining study involving indoor football (Gheidi & Sadeghi, 2010). A total of 455 participants were included: 226 male and 229 females (Appendix 5). Full study details are provided in Table 2.

Table 2. Study Details and Characteristics

Study	Objectives	Participants	Demographic data	Kick type	Leg analysed	Variables	Main outcome
Tant, K.D., and Wilkerson (1991)	Compare the kinematic parameters and temporal structures found between male and female intercollegiate soccer players during the soccer instep kick.	8 males 7 females	Division 1 intercollegiate players Males: Age: 20.7 ± 1.1 years Weight: 72.2 ± 3kg Height: 176.4 ± 2.9cm Females: Age: 20.1 ± 1.5 years Weight: 61.1 ± 2.8kg Height: 151.8 ± 3.3cm	Instep	Dominant kicking leg	Ball velocity Leg joint velocities Leg angular velocities Leg joint torques Kick timing	Males produced significantly higher ball velocities and had longer total movement times than females
Barfield et al. (2002)	Examine selected kinematic differences between elite female and male soccer players in instep kicking with dominant and non-dominant legs.	2 males 6 females	Elite soccer players Age range: 19-22 years Males: Weight: 87.32kg Height: 184.15cm Females: Weight: 60.1kg Height: 164.25cm	Instep	Dominant and non-dominant kicking leg	Ball velocity Leg joint velocities Leg joint angular velocities	Males produced significantly higher ball, toe, and ankle velocities than females on both dominant and non-dominant kicking legs.
Orloff et al. (2008)	Compare the kinetic and kinematic differences of the plant leg position between male and female collegiate soccer players during instep kicking.	11 males 12 females	Amateur Division 3 collegiate players ≥10 years club experience Age: 20.2 ± 1.2 years	Instep	Dominant support leg	Ball velocity Ground reaction forces Leg joint range of motion Trunk range of motion	Females produced significantly greater peak medial-lateral ground reaction forces, trunk inclination and trunk lean compared to males. Anterior-posterior ground reaction forces had high correlation with ball speed.
Shan (2009)	(1) Capture whole body movement of the maximal instep soccer kick of four adult	22 males: 11 novices 11 skilled	Novices: college students, no experience Skilled players: college players, 12 years' experience	Instep	Dominant kicking leg	Ball velocity Centre of gravity excursion Leg range of	Skilled players produced significantly greater ball velocities than novices.

	groups using 3D motion capture. (2) Determine muscle control pattern of skilled players and novices using electromyography. (3) Establish a whole body 15 segment model for determining the influences of gender and training on kicking skill development.	22 females: 11 novices 11 skilled	Novice males: Height: 1.75 ± 0.05m Weight: 72.4 ± 2.7kg Skilled males: Height: 1.76 ± 0.04m Weight: 72.6 ± 2.3kg Novice females: Height 1.65 ± 0.03m Weight 66.3 ± 1.9kg Skilled females: Height: 1.68 ± 0.04m Weight: 67.1 ± 2.0kg			motion Trunk range of motion Muscle lengthening Quality of tension arc	Run up angle and trunk flexion angles were highest in skilled females. Trunk rotation angles were greater in skilled players than novices. Tension arc was only observed in skilled groups. Explosive capacity of muscle groups in skilled players was twice that of novice groups. Anthropometric centre of gravity was higher in females, but peak centre of gravity excursion was highest in skilled males.
R. H. Brophy et al. (2010)	Understand the potential role of kicking in soccer player injuries by comparing lower extremity alignment and muscle activation during kicking between male and female soccer players.	13 males 12 females	High-level collegiate soccer players No history of leg injury Males: Age: 19.8 ± 1.6 years Height: 178.6 ± 8.1cm Weight: 75.0 ± 8.8kg Females: Age: 19.4 ± 1.4 years Height: 166.1 ± 8.0cm Weight: 63.0 ± 8.7kg	Instep Side-foot	Dominant support leg	Ball velocity Leg alignment Leg range of motion Leg muscle activation Kick timing	Ball velocity and phase timing were similar in males and females. Females had significantly greater support leg hip adduction than males. Males had more activation of iliacus in the kicking leg, and gluteus medius and vastus medialis in the support leg than females.
Gheidi and Sadeghi (2010) *	Compare the kinematic variables of ball impact, swing and follow through phases of successful penalty kicks in indoor soccer, from the 6-metre	7 males 7 females	Elite soccer players ≥2 years continuous participation in Iranian indoor soccer league Males: Age: 23 ± 1.7 years Height: 182.2 ± 4.73cm Weight: 72.4 ± 4.04kg BMI: 21.79 ± 0.67	Instep	Dominant kicking leg	Ball velocity Leg range of motion Leg joint velocities Leg joint angular velocities	The general movement pattern of successful and unsuccessful kicks was identical, but successful kicks had lower angular and linear velocity comparing to the unsuccessful ones. This was observed more at the pre-impact

	distance, performed by male and female players.		Females: Age: 23 ± 2.4 years Height: 160.7 ± 4.84cm Weight: 53.7 ± 4.33kg BMI: 20.77 ± 2.29				phase in females and in men at impact, peak and during the follow-through phase.
Sakamoto, Geisler, Nakayama, and Asai (2010)	Identify the fundamental characteristics of ball impact for female players by analysing their movements at the moment of impact and comparing them to those of males.	17 males 17 females	Soccer players ≥5 years playing experience	Instep Inside In-front	Dominant kicking leg	Ball velocity Leg joint velocity Leg angular displacement Coefficient of restitution	Males had significantly higher ball velocities and foot velocities for instep, inside and in-front kicks than females. Males had significantly higher repulsion ratio than females for inside kicks. Males had a straight-line swinging motion while females showed an arc pattern.
Cramer (2009)	Compare the joint angles and ground reaction forces found in the stance leg during the place kick between gender and skill level.	10 males 10 females	High school or collegiate soccer players Age: 14-22 years No history of knee injuries	Place	Dominant support leg	Ground reaction forces Leg joint range of motion	Males had more ankle dorsiflexion and knee flexion than females across both groups. High school players had greater dorsiflexion than college groups Greatest hip flexion was found in collegiate females and least in high school females.
Sakamoto, Geisler, Nakayama, and Asai (2011)	Compare the ball impact kinematics between female and male soccer players to extract the mechanical and technical characteristics of female players.	17 males 17 females	University soccer players Males: ≥10 years of soccer experience Height: 172.0 ± 4.4cm Weight: 65.7 ± 4.8kg Females: ≥5 years of soccer experience Height: 161.4 ± 4.5cm Weight: 56.0 ± 3.4kg	Instep Inside	Dominant kicking leg	Ball velocity Leg joint velocity Leg angular displacement Coefficient of restitution	Males produced higher ball velocity, foot velocity and repulsion ratio than females for both instep and inside kicks Ankle angular displacement was greater for females than males.

Sakamoto, Hong, Tabei, and Asai (2012)	Compare the ball impact and swing motion kinematics between female and male soccer players to deepen the knowledge of mechanical and technical characteristics of female players.	17 males 17 females	University soccer players Males: ≥10 years of soccer experience Height: 172.0 ± 4.4cm Weight: 65.7 ± 4.8kg Females: ≥5 years of soccer experience Height: 161.4 ± 4.5cm Weight: 56.0 ± 3.4kg	Instep	Dominant kicking leg	Ball velocity Leg joint range of motion Leg joint velocity Leg angular displacement Ball-foot velocity ratio	Males produced higher ball velocity, foot velocity, striking mass and ball-to-foot velocity ratio than females for instep and inside kicks. Females had higher ankle angular displacement than males for both kicks. Males had significantly greater hip joint angles than females just before impact for both kicks.
Sakamoto and Asai (2013)	Compare the ball impact and swing motion kinematics between female and male soccer players to deepen the knowledge of mechanical and technical characteristics of female players.	17 males 17 females	University soccer players Males: ≥10 years of soccer experience Height: 172.0 ± 4.4cm Weight: 65.7 ± 4.8kg Females: ≥5 years of soccer experience Height: 161.4 ± 4.5cm Weight: 56.0 ± 3.4kg	Instep Inside	Dominant kicking leg	Ball velocity Leg range of motion Leg joint velocity Leg angular displacement Ball-foot velocity ratio	Males produced significantly higher ball velocity, foot velocity, striking mass and ball-to-foot velocity than females in instep and inside kicks. Females had greater ankle angular displacement for dorsi/plantar flexion and internal/external rotation. Males had greater values for ankle inversion/eversion.
Gonzalez-Jurado, Pérez Amate, and Floría Martín (2012)	Determine efficacy differences in kinematic parameters of the instep kick between men and women.	11 males 11 females	Soccer players Age: 17-19 years ≥5 years' competitive experience No current injuries or illness Males: Players from National League and Spanish 1st Division Females: Players from National Super League and 1st Division	Instep	Dominant kicking leg	Leg joint velocity	Males and females had similar peak hip, knee, and ankle joint velocities. Males had significantly greater foot velocity than females. At impact, hip and knee velocity was higher in females than males, while ankle and foot velocity was higher in males.

							Both sexes showed a proximal-to-distal energy transfer pattern.
Shan et al. (2012)	Investigate the specific relationships between hip range of motion, last stride length and tension arc in order to fulfil the user-friendly method with reliability comparable to the 3D movement analysis for the quality evaluation of maximal instep kick.	24 males 26 females	Age: 21.7 ± 2.2 years Novices: College students with no soccer experience Skilled: College athletes with 12 years' experience Novice males: Height: 1.75 ± 0.05m Weight: 72.4 ± 2.7kg Skilled males: Height: 1.76 ± 0.04m Weight: 72.6 ± 2.3kg Novice females: Height: 1.65 ± 0.03m Weight: 66.3 ± 1.9kg Skilled females: Height: 1.68 ± 0.04m Weight: 67.1 ± 2.0kg	Instep	Dominant kicking leg	Ball velocity Leg joint range of motion Trunk range of motion Quality of tension arc	Ball velocity, shoulder and hip flexion/ extension, trunk rotation and last stride length were significantly higher for skilled players than novices. Trunk rotation in females and knee flexion/extension in males were significantly greater in skilled than novice groups. These variables were deemed reliable predictors of kick quality.
Sakamoto, Shimizu, Yamada, Hong, and Asai (2013)	Use a three-dimensional motion-capture system to compare swing velocities and joint torques between male and female players to better understand the features of kicking motion in female soccer players.	13 males 13 females	Collegiate players Males: Height: 174.3 ± 4.7cm Weight: 66.8 ± 4.9kg Females: Height: 160.4 ± 4.9cm Weight: 57.1 ± 5.7kg	Instep	Dominant kicking leg	Ball velocity Foot velocity Knee joint torque Leg energies	Males produced significantly higher ball and foot velocities than females. Males had significantly higher peak flexion/ extension and abduction/ adduction knee joint torques than females. Males had higher thigh and shank energies and ratios than females.

Sakamoto, Sasaki, Hong, Matsukura, and Asai (2014)	(1) Compare the instep kick motions of female and male athletes using an optical motion capture system and clarify the technical characteristics of the motion in female soccer players. (2) Examine technical factors that contribute to increasing ball velocity.	13 males 13 females	Collegiate players Males: Height: 174.3 ± 4.7cm Weight: 66.8 ± 4.9kg Females: Height: 160.4 ± 4.9cm Weight: 57.1 ± 5.7kg	Instep	Dominant kicking leg	Ball velocity Leg joint velocity Leg joint torques Leg energies	Males produced significantly higher ball and foot velocities than females. Males had significantly higher peak flexion/ extension and abduction/adduction knee joint torques than females. Males had higher peak hip torques in all planes. Both sexes showed a proximal-to-distal energy transfer pattern. Males had higher thigh and shank energies and ratios than females. Swing velocity tended to increase with increasing vertical force of the hip joint.
Katis, Amiridis, Kellis, and Lees (2014)	(1) Investigate powerful kick recovery after fatigue produced by intense periods of running. (2) Examine whether fatigue responses are gender specific.	10 males 10 females	Amateur players ≥8 years' experience, training 3/week, 1 game/week No underlying health issues Males: Age: 26.3 ± 4.9 years Height: 178.1 ± 5.1cm Weight: 81.3 ± 8.1kg Females: Age: 24.4 ± 4.2 years Height: 169.7 ± 5.7cm Weight: 61.8 ± 5.1kg	Instep	Dominant kicking leg	Ball velocity Leg joint range of motion Leg joint velocities Leg joint angular displacement	Ball velocity, peak ankle, knee, and hip velocity, and at impact knee velocity were significantly reduced in the first two post-fatigue trials for both sexes. Both sexes had lower ankle plantar flexion angles at impact, while males had reduced knee flexion and females had higher hip abduction angles post-fatigue Fatigue affected ankle and knee in males, and ankle and hip kinematics in females. Fatigue effects recovered to pre-fatigue levels by the third trial.

Katis et al. (2015) **	Examine whether differences in powerful kicking performance between males, females and pubertal players are accompanied by differences in movement and temporal kinematics.	10 males 10 females 10 prepubertal males	Amateur soccer players Training 2-3/week, 1 game /week Males: Age: 25.3 ± 4.9 years Height: 179 ± 4.6cm Weight: 80.8 ± 6.4kg Training age: 12.5 ± 2.9 years Females: Age: 24.9 ± 3.5 years Height: 167.4 ± 4.2cm Weight: 62.2 ± 3.7kg Training age: 9.7 ± 3.1 years Pre-pubertal males: Age: 15.1 ± 0.7 years Height: 143.2 ± 35.2cm Weight: 47.1 ± 13.2kg Training age: 4.9 ± 0.9 years	Instep	Dominant kicking leg	Ball velocity Leg joint range of motion Leg joint velocity Leg joint angular velocity Leg angular displacement Ball-foot velocity ratio	Males had significantly higher ball velocity, knee and hip linear velocity, and ankle and knee angular velocity compared to females and pre-pubertal males. Ball-to-foot velocity ratio was highest in males and lowest in females. Peak hip and ankle linear velocity occurred significantly later in males than females and pre-pubertal males. Males had higher ankle plantarflexion lower inversion and higher hip flexion angles prior to impact.
Navandar et al. (2016)	Study the effect of gender on the leg dominance in kicking in soccer players.	45 elite soccer players 19 males 26 females	Elite soccer players Males: Reserve team players of 1st division club playing in Spanish Football 3rd Division Females: Players from 1st Division teams in the Spanish Women's League	Instep	Dominant and non-dominant kicking leg	Ball velocity Leg joint range of motion Leg joint velocities Leg angular velocities Leg angular displacement Kick timing	Ball and toe velocities were higher in males than females for both limbs. Females had higher peak linear ball and toe velocities when kicking with their dominant leg than their non-dominant legs. Females had greater knee flexion angles at impact with their non-dominant leg.

Navandar et al. (2017) ***	Ascertain if the influence of leg dominance on kicking is affected by a previous hamstring injury to either leg.	19 males 26 females	Elite soccer players Males: Age: 21.16 ± 2.00 years Weight: 71.46 ± 6.22kg Females: Age: 22.15 ± 4.50 years Weight: 60.71 ± 9.48kg	Instep	Dominant and non-dominant kicking leg	Ball velocity Leg joint range of motion Leg joint velocities Hip angular velocity Knee joint moments Hip joint moments	Differences in peak linear velocities between dominant and non-dominant limbs were only found for the uninjured group. In the backswing phase, dominant limb kicks had greater hip flexion moments than non-dominant in the uninjured group. Uninjured players produced greater hip flexion velocity in the dominant limbs at the end of the leg cocking phase. During follow through, there was a significant difference in limb dominance for the uninjured group for the peak hip extension moment. Uninjured females had greater knee flexion in non-dominant legs at impact. Injured females had lower knee flexion angles at impact in non-dominant limbs.

Navandar, Veiga, Torres, Chorro, and Navarro (2018)	Evaluate the effect of sex and leg dominance on kicking in legs with and without a previous hamstring injury.	19 males 26 females	Elite soccer players Uninjured and match fit Males: Reserve players for a Spanish 1st Division club in Segunda Division Age: 21.16 ± 2.00 years Weight: 71.46 ± 6.22kg Females: Players from 2 teams in Spanish Women's 1st Division Age: 22.15 ± 4.5 years Weight: 60.71 ± 9.48kg	Instep	Dominant and non-dominant kicking leg	Ball velocity Leg joint range of motion Leg joint velocity Leg joint angular velocity Leg joint moments	The backswing phase was shorter for both sexes in non-dominant leg kicks for the injured group. Injured females had lower knee flexion at the end of this phase. Injured females had significantly smaller peak hip linear velocity during backswing when kicking with the dominant leg. In the leg cocking phase, injured females had lower hip flexion velocity especially in non-dominant leg kicks. Kinematic and kinetic variables were similar for both groups and sexes in the leg acceleration and follow through phases.
Sakamoto, Numazu, Hong, and Asai (2016)	Examine the technical characteristics related to the swinging motions of female players by focusing on the instep kicking motions of university male and female soccer players.	6 males 6 females	University soccer players Males: Height: 175.0 ± 5.8cm Weight: 66.4 ± 6.8kg Females: Height: 158.7 ± 6.7cm Weight: 58.0 ± 5.7kg	Instep Side-foot	Dominant kicking leg	Ball velocity Leg joint velocity Leg joint torques	Males had significantly higher ball and foot velocities than females for both kicks. Peak flexion/ extension and abduction/ adduction hip torques were significantly higher in males than females for instep kicks. Peak abduction/ adduction hip torques were higher for males than females for side-foot kicks. Males had higher knee torques in all planes than females for both kicks.

Smith and Gilleard (2016)	Investigate differences in joint angular displacement, ball and foot velocity between males and females performing a standardised lofted instep kick.	6 males 7 females	Experienced amateur soccer players Playing in top division of regional league Males: Age: 22.3 ± 3.4 years Height: 182.0 ± 4.0cm Weight: 81.9 ± 10.8kg Females: Age: 25.3 ± 7.6 years Height: 164.8 ± 4.8cm Weight: 68.5kg ± 9.7kg	Instep	Dominant kicking leg	Ball velocity Leg joint range of motion Trunk range of motion Leg joint angular velocity Leg angular displacement Trunk angular displacement	All male players achieved a kick distance of 35 metres, compared to half of females. Females had significantly greater peak hip extension and abduction at impact, as well as increased anterior pelvic tilt and transverse rotation of the thorax. Males had significantly greater ankle plantarflexion and ball velocity.
Chanda and Mondal (2018)	(1) Establish the comparative relationship of the kicking leg in the soccer instep kick. between males and females (2) Investigate supporting kinematic factors. (3) Find ratio difference in kicked ball velocity between the 2 genders.	10 males 10 females	Elite soccer players Players from 17 years Bangladesh National Women's team camp at Kamalapur Stadium, Dhaka and Bangladesh Krira Shikkha Protishtan, Dhaka who have played for their national team at any age to senior level. Age: 16-22 years	Instep	Dominant kicking leg	Ball velocity Leg joint range of motion Leg joint angular velocity Leg joint angular displacement	Ball velocity produced by males was twice that of females. Mean hip angles and angular displacement were higher in females than males. Angular velocity of the kicking leg knee at impact was three times higher in males than females. Females had a greater knee angle at follow through. Males had higher knee angular displacement than females. Ankle angle decreased in males from ground contact to ball contact but increased in females, who also had a higher mean angular displacement. Angular velocity of the ankle was higher in females at impact.

Abbreviations: 3D – three-dimensional; ≥ - equal to or greater than; / - per; instep – kick performed with the instep/superior portion of the foot; inside – type of kick performed with the inside/medial border of the foot; side-foot – type of kick performed with the inside/medial border of the foot; in-front – type of kick performed with the supero-medial border of the foot, between the instep and inside portions of the foot; place – type of kick performed with a stationary ball used in soccer for goal kicks, corner kicks, and penalty kicks and rugby for conversions and penalties.

Most studies made their main research comparison between male and female athletes except:
* - Gheidi and Sadeghi (2010) compared successful and unsuccessful kicks in male and female athletes.
** - Katis et al. (2015) compared males, females, and pre-pubertal players.
*** - Navandar et al. 2 (2017) examined kicking using dominant and non-dominant legs with and without a previous hamstring injury in male and female athletes.

2.5.1 Kinematics

2.5.1.1 Ball Velocity

Sixteen studies investigated the velocity of the ball during kicks (Figure 7) (Appendix 6) (Barfield et al., 2002; R. H. Brophy et al., 2010; Chanda & Mondal, 2018; Katis et al., 2014; Katis et al., 2015; Navandar et al., 2016, 2017; Navandar et al., 2018; Orloff et al., 2008; Sakamoto & Asai, 2013; Sakamoto et al., 2010, 2011; Sakamoto et al., 2012; Sakamoto et al., 2016; Sakamoto et al., 2014; Sakamoto et al., 2013; Shan, 2009; Shan et al., 2012; Smith & Gilleard, 2016; Tant et al., 1991). Males produced significantly higher mean (Figure 7A), peak (Figure 7B), and instantaneous post-impact ball velocities (Figure 7C) than females. Males and females with previous kicking experience achieved greater ball velocities than their novice counterparts, with skilled female athletes performing higher velocity kicks than novice males (Shan, 2009). When kicking styles were compared, instep kicks produced the highest ball velocities across both sexes (Sakamoto & Asai, 2013; Sakamoto et al., 2011; Sakamoto et al., 2012).

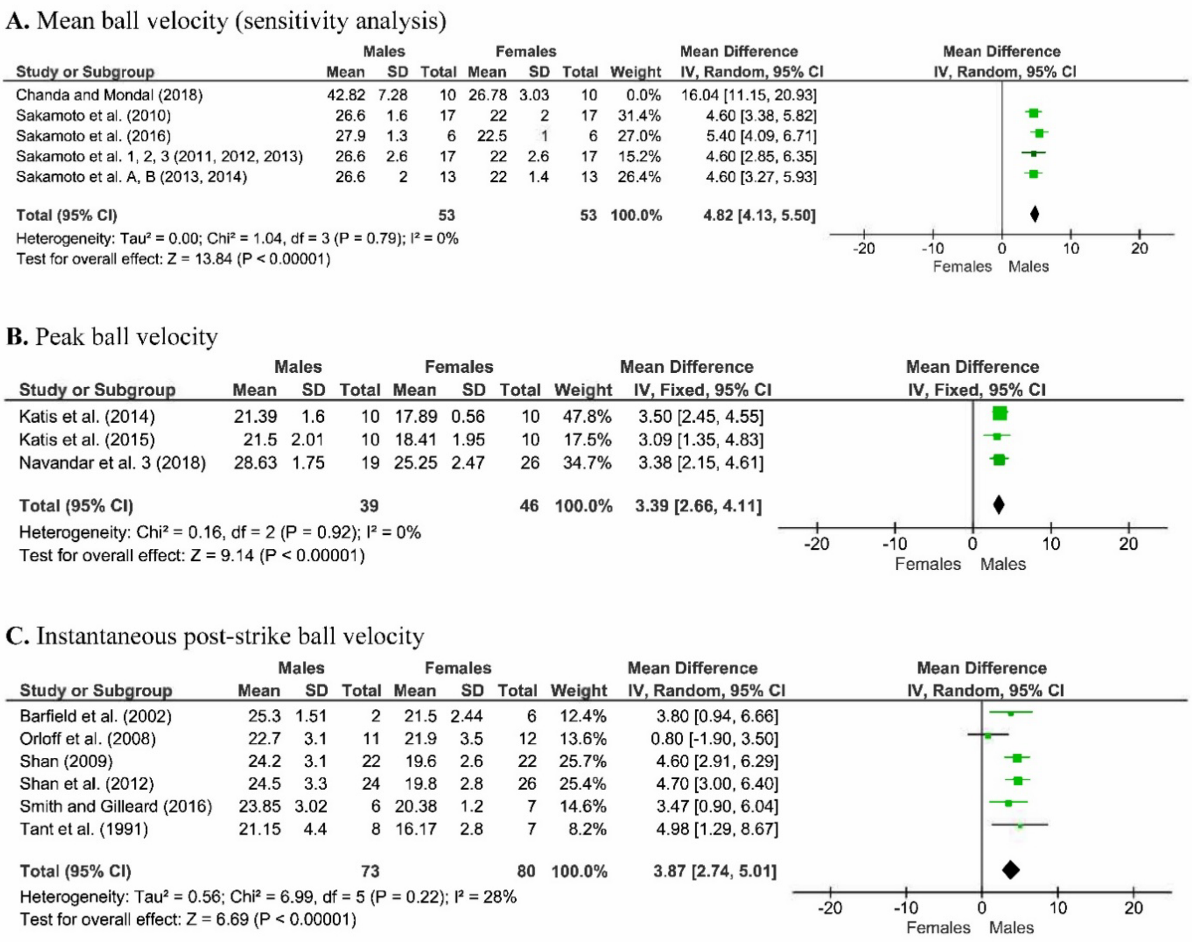


Figure 7. Forest plots of meta-analyses comparing ball velocities in males and females. **A.** Mean ball velocity (sensitivity analysis). **B.** Peak ball velocity. **C.** Instantaneous post-strike ball velocity.

2.5.1.2 Linear Velocity

Kicking leg linear velocities were evaluated in 12 studies (Figure 8) (Appendix 7), considering joints (ankle, knee, hip) and individual leg segments (toe, foot).

Ankle. Peak ankle joint linear velocity was examined in five studies (Barfield et al., 2002; Gheidi & Sadeghi, 2010; Gonzalez-Jurado et al., 2012; Katis et al., 2015; Navandar et al., 2016, 2017; Navandar et al., 2018). Males had significantly greater maximal ankle velocities compared to females (Figure 8A). When kicking accuracy was compared, females had higher peak ankle linear velocities during successful shots on target, while males produced greater ankle velocities during inaccurate kicks.

Knee. Investigated in five studies (Gheidi & Sadeghi, 2010; Gonzalez-Jurado et al., 2012; Katis et al., 2014; Katis et al., 2015; Navandar et al., 2017; Navandar et al., 2018), peak knee extension velocity was significantly greater in males than females (Figure 8B). Unsuccessful kicks had significantly higher peak knee velocities than accurate kicks for both sexes (Gheidi & Sadeghi, 2010).

Hip. Hip velocity was examined in four studies (Gheidi & Sadeghi, 2010; Gonzalez-Jurado et al., 2012; Katis et al., 2015; Navandar et al., 2017; Navandar et al., 2018), with no significant difference between the sexes for peak velocities (Figure 8C). Hip velocity was found to be higher in unsuccessful kicks, except peak velocity, which was highest in successful kicks in females (Gheidi & Sadeghi, 2010).

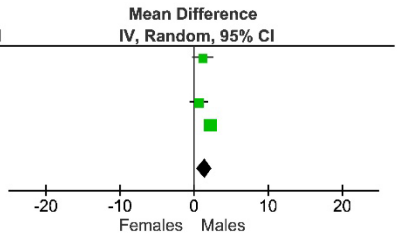
Toe and Foot. Peak toe linear velocity towards the ball during kicks was significantly greater in male players than females (Figure 8D) (Barfield et al., 2002; Gheidi & Sadeghi, 2010; Navandar et al., 2016, 2017). Inaccurate kicks produced higher toe velocities than accurate kicks for both sexes (Gheidi & Sadeghi, 2010). Mean foot linear velocity was greater in males than females before ball contact (Figure 8E) (Sakamoto & Asai, 2013; Sakamoto et al., 2010, 2011; Sakamoto et al., 2012; Sakamoto et al., 2016; Sakamoto et al., 2013; Smith & Gilleard, 2016) and at peak (Gonzalez-Jurado et al., 2012). Males produced higher foot velocities than females, irrespective of kick type; for both sexes, instep kicks yielded the greatest foot velocities (Sakamoto et al., 2010, 2011).

When the lower limb linear velocities of male and female kickers were compared, males achieved higher values across all joints and segments, with the relative magnitudes of significance increasing distally.

A. Peak ankle linear velocity (sensitivity analysis)

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Gheidi and Sadeghi (2010)	12.36	1.75	7	11.18	0.76	7	26.7%	1.18 [-0.23, 2.59]
Gonzalez-Jurado et al. (2012)	16.62	1.9	11	11.86	0.032	11	0.0%	4.76 [3.64, 5.88]
Katis et al. (2015)	13.41	1.65	10	12.77	1.21	10	29.6%	0.64 [-0.63, 1.91]
Navandar et al. 1 (2016)	18.32	0.95	19	16.12	1.37	26	43.7%	2.20 [1.52, 2.88]
Total (95% CI)			**36**			**43**	**100.0%**	**1.47 [0.44, 2.49]**

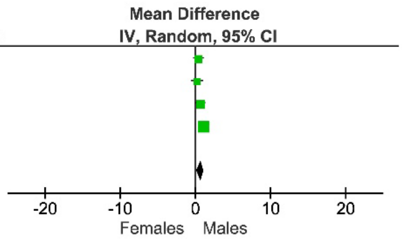
Heterogeneity: Tau² = 0.51; Chi² = 5.26, df = 2 (P = 0.07); I² = 62%
Test for overall effect: Z = 2.80 (P = 0.005)



B. Peak knee linear velocity

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Gheidi and Sadeghi (2010)	7.44	0.76	7	7.04	0.6	7	21.0%	0.40 [-0.32, 1.12]
Gonzalez-Jurado et al. (2012)	6.56	1.02	7	6.37	0.45	7	17.3%	0.19 [-0.64, 1.02]
Katis et al. (2015)	7.96	0.69	10	7.29	0.74	10	24.8%	0.67 [0.04, 1.30]
Navandar et al. 3 (2018)	10.13	0.62	19	9.05	0.81	26	36.9%	1.08 [0.66, 1.50]
Total (95% CI)			**43**			**50**	**100.0%**	**0.68 [0.28, 1.09]**

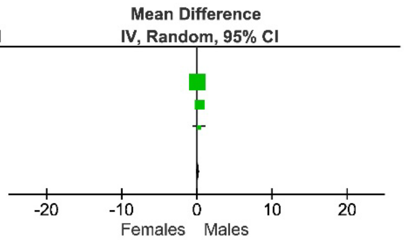
Heterogeneity: Tau² = 0.07; Chi² = 5.13, df = 3 (P = 0.16); I² = 41%
Test for overall effect: Z = 3.29 (P = 0.001)



C. Peak hip linear velocity (sensitivity analysis)

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Gheidi and Sadeghi (2010)	3.71	0.09	7	2.84	0.08	7	0.0%	0.87 [0.78, 0.96]
Gonzalez-Jurado et al. (2012)	3.05	0.32	11	3	0.31	11	62.0%	0.05 [-0.21, 0.31]
Katis et al. (2015)	3	0.41	10	2.63	0.43	10	31.7%	0.37 [0.00, 0.74]
Navandar et al. 3 (2018)	4.38	0.62	19	4.1	2.03	26	6.3%	0.28 [-0.55, 1.11]
Total (95% CI)			**40**			**47**	**100.0%**	**0.17 [-0.04, 0.37]**

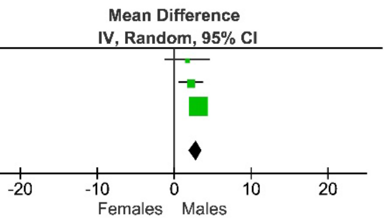
Heterogeneity: Tau² = 0.00; Chi² = 2.00, df = 2 (P = 0.37); I² = 0%
Test for overall effect: Z = 1.57 (P = 0.12)



D. Peak toe linear velocity

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Barfield et al. (2002)	20.4	1.3	2	18.7	2.9	6	6.9%	1.70 [-1.24, 4.64]
Gheidi and Sadeghi (2010)	17.16	1.62	7	15	1.4	7	23.7%	2.16 [0.57, 3.75]
Navandar et al. 1 (2016)	22.81	1.11	19	19.7	2.03	26	69.4%	3.11 [2.18, 4.04]
Total (95% CI)			**28**			**39**	**100.0%**	**2.79 [2.02, 3.56]**

Heterogeneity: Tau² = 0.00; Chi² = 1.59, df = 2 (P = 0.45); I² = 0%
Test for overall effect: Z = 7.08 (P < 0.00001)



E. Mean foot linear velocity

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Sakamoto et al. (2016)	21.2	6.86	6	17.8	1.4	6	7.7%	3.40 [-2.20, 9.00]
Sakamoto et al. 1, 2, 3 (2011, 2012, 2013)	20.5	2.2	17	18	1.8	17	42.1%	2.50 [1.15, 3.85]
Smith and Gilleard (2016)	16.37	1.04	6	15.77	0.37	7	50.1%	0.60 [-0.28, 1.48]
Total (95% CI)			**29**			**30**	**100.0%**	**1.62 [-0.06, 3.29]**

Heterogeneity: Tau² = 1.25; Chi² = 5.95, df = 2 (P = 0.05); I² = 66%
Test for overall effect: Z = 1.89 (P = 0.06)

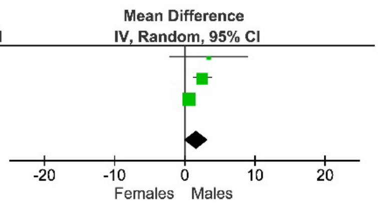


Figure 8. Forest plots of meta-analyses comparing linear joint velocities in males and females. **A.** Peak ankle linear velocity (sensitivity analysis). **B.** Peak knee linear velocity. **C.** Peak hip linear velocity (sensitivity analysis). **D.** Peak toe linear velocity. **E.** Mean foot linear velocity.

2.5.1.3 Meta-analysis of Ball and Joint Velocity.

A meta-analysis using random effects and sensitivity analysis indicated that males produced significantly greater ball velocities than females for mean (mean difference (MD) 4.82m/s; 95% CI = 4.13 to 5.50; I^2 = 0%) (Figure 7A), peak (MD = 3.39m/s; 95% CI = 2.66 to 4.11; I^2 = 0%) (Figure 7B), and instantaneous post-ball strike (MD = 3.87m/s; 95% CI = 2.74 to 5.01; I^2 = 28%) (Figure 7C) velocities. The greatest difference in linear limb velocities between the sexes was found at the distal joints and segments of the lower limb. Peak ankle (MD = 1.47m/s; 95% CI = 0.44 to 2.49; I^2 = 62%) (Figure 8A) and toe (MD = 2.79m/s; 95% CI = 2.02 to 3.56; I^2 = 0%) (Figure 8D), and mean foot (MD = 1.62m/s; 95% CI = -0.06 to 3.29; I^2 = 66%) (Figure 8E) linear velocities were significantly higher in males than females. Mean differences between the sexes were smaller for peak velocities at the proximal joints of the knee (MD=0.68m/s, 95% CI= 0.28 to 1.09, I^2=50%) (Figure 8B) and hip (MD= 0.17m/s, 95% CI= -0.04 to 0.37, I^2= 0%) (Figure 8C). Sensitivity analyses were performed on three outcomes that exhibited high levels of heterogeneity (I^2>75%): mean ball velocity (Figure 7A), peak ankle linear velocity (Figure 8A), and peak hip linear velocity (Figure 8C). Pre-sensitivity analysis results can be found in Appendix 8. The remaining variables examined in this review were deemed inappropriate for meta-analysis due to a lack of consistency in reporting of data across studies and the limited number of studies investigating each of them.

2.5.1.4 Range of Motion

Kicking leg joint angles throughout the kicking movement were examined in nine studies (Appendix 9) (Chanda & Mondal, 2018; Gheidi & Sadeghi, 2010; Katis et al., 2014; Navandar et al., 2016, 2017; Navandar et al., 2018; Sakamoto et al., 2012; Shan, 2009; Smith & Gilleard, 2016)

Females produced greater peak hip extension angles than males prior to heel strike and hip abduction angles prior to ball impact (Smith & Gilleard, 2016). Males had greater mean hip flexion angles before ball impact (Sakamoto et al., 2012), at ball impact (Gheidi & Sadeghi, 2010), and during the follow-through of the kick (Chanda & Mondal, 2018). Males used greater knee flexion angles than females before (Sakamoto et al., 2012) and at ball impact (Gheidi & Sadeghi, 2010), while women had greater knee flexion during the follow-through phase of the kick (Chanda & Mondal, 2018). Male players had significantly greater ankle plantar flexion angles than females of the same experience level at the point of ball impact (Gheidi & Sadeghi, 2010; Smith & Gilleard, 2016). Accurate kicks had significantly less ankle plantarflexion than inaccurate kicks for both sexes (Gheidi & Sadeghi, 2010).

Trunk flexion range of motion was significantly greater in females than males at the point of ball contact (Orloff et al., 2008). Female players had significantly greater trunk side flexion just before ball contact than males (Orloff et al., 2008).

2.5.1.5 Joint Angular Velocity and Displacement

The angular velocity of lower limb joints was investigated in five studies (Appendix 10) (Barfield et al., 2002; Chanda & Mondal, 2018; Katis et al., 2015; Navandar et al., 2016, 2017; Navandar et al., 2018; Tant et al., 1991). Males produced significantly higher knee joint angular velocity than females at peak (Katis et al., 2015) and at impact (Chanda & Mondal, 2018), with no significant difference in hip joint angular velocity between the sexes at peak (Katis et al., 2015; Navandar et al., 2016, 2017; Navandar et al., 2018; Tant et al., 1991) or at ball impact (Chanda & Mondal, 2018).

Five studies investigated ankle joint angular displacement during kicking (Appendix 11) (Chanda & Mondal, 2018; Katis et al., 2014; Sakamoto & Asai, 2013; Sakamoto et al., 2011; Sakamoto et al., 2012; Smith & Gilleard, 2016). Females were found to have greater dorsi/plantarflexion (Chanda & Mondal, 2018; Sakamoto & Asai, 2013; Sakamoto et al., 2011; Sakamoto et al., 2012), and internal/external rotation angular displacements (Sakamoto & Asai, 2013; Sakamoto et al.,

2012) than their male counterparts. Males produced larger ankle inversion/eversion angular displacements for instep and inside kicks than females (Sakamoto & Asai, 2013).

2.5.2 Kinetics

Kicking leg joint torques were investigated in two studies (Appendix 12) (Sakamoto et al., 2016; Sakamoto et al., 2014; Sakamoto et al., 2013). Peak knee joint flexion/extension and adduction/abduction torques were greater for male players than females during forward swing of the kicking movement (Sakamoto et al., 2014; Sakamoto et al., 2013). Hip flexion/extension torques were the highest of all torques produced by both sexes (Sakamoto et al., 2014). Male players had higher peak torque values than females for all ranges of hip motion during forward swing (Sakamoto et al., 2014). There was no difference in hip and knee joint moments for males and females throughout the kick phases (Appendix 12) (Navandar et al., 2017; Navandar et al., 2018). Combined potential and kinetic energies of the thigh and shank were greater for male players than females, resulting in larger thigh-to-shank energy transfer values for males (Sakamoto et al., 2014; Sakamoto et al., 2013). Both sexes followed the same kicking pattern of proximal-to-distal sequencing (Sakamoto et al., 2014).

Studies examining the creation of a whole-body tension arc during kicks compared participants based on their sex and soccer playing experience (Shan, 2009; Shan et al., 2012). Significant differences were found between novice females and both male groups, and between skilled females and novice females, as only experienced players produced a tension arc (Appendix 13) (Shan, 2009).

Ball-to-foot velocity ratios, also described as repulsion ratios and coefficients of restitution, are summarised in Appendix 14 (Sakamoto & Asai, 2013; Sakamoto et al., 2010, 2011; Sakamoto et al., 2012). Male players had a significantly higher coefficient of restitution than females

(Sakamoto et al., 2010). Mean ball-to-foot velocities were substantially lower in female kickers compared to males (Sakamoto & Asai, 2013; Sakamoto et al., 2011; Sakamoto et al., 2012).

2.5.3 Risk of Bias

The risk of bias for the included studies is presented in Table 3. There were several common issues identified across all papers in a number of the tool's domains. Convenience sampling and a lack of demographic data presented in the majority of studies introduced a risk of bias as the participants may not accurately represent the target population. None of the included studies addressed the issue of non-responders. Almost all studies failed to declare funding sources and potential conflicts of interest, while several did not document participant consent or ethical approval. Overall, most studies were found to be of moderate to poor quality.

Table 3. Critical Appraisal of Included Studies using the AXIS Tool

	Tant et al. (1991)	Barfield et al. (2002)	Orloff et al. (2008)	Shan (2009)	R. H. Brophy et al. (2010)	Gheidi and Sadeghi (2010)	Sakamoto et al. (2010)	Cramer (2009)	Sakamoto et al. (2011)	Sakamoto et al. (2012)	Sakamoto and Asai (2013)	Gonzalez-Jurado et al. (2012)	Shan et al. (2012)	Sakamoto et al. (2013)	Sakamoto et al. (2014)	Katis et al. (2014)	Katis et al. (2015)	Navandar et al. (2016)	Navandar et al. (2017)	Navandar et al. (2018)	Sakamoto et al. (2016)	Smith and Gilleard (2016)	Chanda and Mondal (2018)
Introduction																							
Were the aims/ objectives of the study clear?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Methods																							
Was the study design appropriate for the stated aim(s)?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Was the sample size justified?	N	N	N	Y	Y	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
Was the target reference population clearly defined?	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	Y	Y	Y
Was the sample taken from an appropriate population base so that	Y	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	Y	U	Y	Y	U	Y	Y	U	U	Y	Y	Y

it closely represented the target/ reference population under investigation?																							
Was the selection process likely to select participants who were representative of the target/ reference population under investigation?	N	N	N	U	U	U	N	N	U	U	U	U	N	U	U	U	N	U	U	N	U	N	U
Were there measures undertaken to address and categorise non-responders?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Were the risk factor and outcome variables measured appropriately to the aims of the study?	U	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Were the risk factor and outcome variables measured correctly using instruments / measurements that had been trialled, piloted, or published previously?	U	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Is it clear what was used to determine statistical significance and/or precision estimates	N	Y	N	Y	Y	N	N	N	N	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N

(e.g. values, CIs)?																							
Were the methods (including statistical methods) sufficiently described to enable them to be repeated?	N	Y	N	Y	Y	N	N	N	N	N	Y	N	Y	N	N	Y	Y	N	N	Y	N	Y	N
Results																							
Were the basic data adequately described?	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N
Does the response rate raise concern about non-responders bias?	U	U	U	U	U	U	U	N	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U

If appropriate, was information about the non-responders described?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Were the results internally consistent?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Were the results for the analyses described in the methods presented?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	U
Discussion																							
Were the author's discussions and conclusions justified by the results?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Were the limitations of the study discussed?	N	N	N	N	Y	N	N	Y	N	N	N	N	Y	N	N	Y	N	N	N	Y	N	Y	N

Were there any funding sources or conflicts of interest that may affect the author's interpretation of the results?	U	U	U	U	N	U	U	U	U	U	U	U	U	U	N	U	N	U	U	U	U	U	U
Was ethical approval or consent of participants attained?	U	Y	U	Y	Y	U	U	Y	U	U	Y	Y	Y	Y	U	Y	Y	U	U	Y	Y	Y	U

Legend: Coloured text indicates the following: Green = positive impact on quality of study; Red = negative impact on quality of study; Orange = unknown impact on quality of study. Y = yes; N = no; U = unsure. Based on scoring system used by McHugh et al. (2019)(McHugh et al., 2019)

2.6 Discussion and Implications

Males produced significantly greater ball and distal linear joint velocities during soccer kicks compared to females. Skilled players of both sexes used tension arcs to generate power; a technique not used by novices. The main findings of this systematic review are summarised in Figure 9.

Figure 9. Graphical comparison of male and female kicking biomechanics.
Image designed using resources created by Freepik. Source: Freepik.com.

2.6.1 Ball Velocity

The most definitive difference between male and female kickers relates to ball velocity, with 12 studies reporting that males produced significantly greater ball velocities than females (Figure 7). Producing high ball velocity is one of the most important outcomes of a kick in soccer (Bekris et al., 2015). In goal kicking scenarios, it increases the chances of scoring; in open play, it is fundamental to the execution of long passes (Dörge et al., 2002). As such, ball velocity is deemed to be a key biomechanical indicator of kicking performance (Sinclair, Fewtrell, et al., 2014) and a measure of kicking success (A. Lees & Nolan, 1998). The difference between male and female athletes' ball velocities may contribute to different playing styles. Female players use powerful instep kicks more often than their male counterparts, even when performing short passes, and take shots on goal from a closer distance to the target than men (Althoff, Kroiher, & Hennig, 2010). These adaptations may arise in an effort by female athletes to achieve optimal outcomes despite their lower ball velocities.

The anthropometric and physiological variation between the sexes may contribute to the differences in ball velocity. Males tend to be taller (Garcia & Quintana-Domeque, 2007) and heavier (Mascherini et al., 2018b) than females, as evidenced by the studies included in this review (Appendix 5). A positive relationship exists between body size and absolute strength (van den Tillaar & Ettema, 2004). Greater body size is associated with higher ball velocity across a variety of sports (Debanne & Laffaye, 2011; van den Tillaar & Ettema, 2004; Wong et al., 2014). Taller individuals are thought to perform better in activities with a strength component (van den Tillaar & Ettema, 2004); perhaps due to the mechanical advantage created by their longer limbs (Reeves, Varakamin, & Henry, 1996). Males have a higher proportion of lean muscle mass (Nieves et al., 2005; Schorr et al., 2018), while females have a greater fat mass index (Mascherini et al., 2018b; Wells & Plowman, 1983), particularly in the lower limbs (Lemieux et al., 1994). Reduced muscle mass in females results in 33% lower leg strength, compared to their male counterparts (Miller et al., 1993). Accurate kickers exhibit larger quantities of relative lean mass and less relative fat mass in their kicking limbs compared to their inaccurate counterparts (N. H. Hart, Nimphius, Spiteri, Cochrane, & Newton, 2016), putting female kickers at a disadvantage for both the velocity and accuracy of their kicks.

2.6.2 Lower Limb Linear Velocities

Kicking is a swinging motion which follows a sequence of proximal-to-distal segmental movements (A. Lees & Nolan, 1998). Both male and female players showed evidence of proximal-to-distal sequencing during kicks (Gonzalez-Jurado et al., 2012; Sakamoto et al., 2014; Sakamoto et al., 2013). However, the results of this review indicate that male athletes perform this action more efficiently, as males had significantly greater distal lower limb joint linear velocities than females, despite similar peak hip velocities. Sakamoto and colleagues reported that male soccer players produced higher hip and knee joint torques than their female counterparts during instep and inside kicks (Sakamoto et al., 2016; Sakamoto et al., 2014; Sakamoto et al., 2013). This greater rotational force may stem from increased hip musculature activation exhibited by males in their kicking leg during kicks (R. H. Brophy et al., 2010), as well as their larger body mass. The potential and kinetic energies of the thigh and shank were higher in male athletes than females, which resulted in a greater thigh-to-shank energy transfer value for males (Sakamoto et al., 2014; Sakamoto et al., 2013). Distal limb segment velocity at ball contact plays a significant role in fast kicking performance (Dörge et al., 2002); males produced significantly higher velocities than females at the ankle, foot, and toe. The optimal sequencing and energy transfer pattern from proximal to distal limb segments seen in males may be a contributing factor to their high ball velocities.

2.6.3 Joint Range of Motion

Male kickers exhibited significantly more ankle plantarflexion than females at ball contact (Gheidi & Sadeghi, 2010; Katis et al., 2015; Smith & Gilleard, 2016). While males maintained this position for the duration of the kick, females fluctuated throughout, exhibiting greater ankle angular displacements of dorsiflexion/plantarflexion and internal rotation/external rotation (Chanda & Mondal, 2018; Sakamoto & Asai, 2013; Sakamoto et al., 2011; Sakamoto et al., 2012). This may have been an attempt by female athletes to achieve optimum foot positioning to strike the ball or as a result of reduced muscular strength to control the ankle movement throughout the kick (Katis et al., 2015; Smith & Gilleard, 2016). When performing maximal effort kicks, soccer players tend strike the ball with the instep portion of their foot, as this style of kick produces the greatest ball velocity (Kellis & Katis, 2007). The fastest instep kicks are achieved when the foot is maximally plantarflexed at ball contact (Asami & Nolte, 1983), as this is a position of peak stability (Katis et al., 2015). Male players had a more consistent angle of ankle plantarflexion, higher coefficient of restitution, and greater resultant ball velocity during kicks than females (Sakamoto & Asai, 2013; Sakamoto et al., 2011; Sakamoto et al., 2012), which may have contributed to their increased ball velocity.

Female players had significantly greater trunk forward flexion at ball contact than males (Shan, 2009; Shan et al., 2012) due to variation in momentum dissipation techniques. Males followed through with a jump after powerful kicks to slow their forward movement, while females counteracted this momentum using upper body flexion (Shan, 2009). This produced a different ball release direction in females, compensated for by a greater approach angle to the ball (Shan, 2009). Trunk range of motion may represent a key difference in kicking technique between the sexes.

2.6.4 The Impact of Experience

Comparison of skill level in this review yielded some interesting results. Skilled players kick using a different technique to their novice counterparts; namely the formation of a tension arc (Shan, 2009). This is achieved through kicking-side hip extension, knee flexion, and trunk rotation to the non-kicking side, and compounded by extension and abduction of the non-kicking side arm (Shan & Westerhoff, 2005). The tension arc acts to increase the potential energy in the muscles, facilitating greater acceleration of the limb segments, and is released in a segmental pattern towards the ball (Langhout, Tak, van der Westen, & Lenssen, 2017). Among skilled players, males achieved greater muscular pre-stretch which allowed them to create tighter, better quality tension arcs than females (Shan, 2009). This results in higher ball velocities among male skilled players (Shan, 2009). Experienced female athletes produced greater ball velocities than novice males. This indicates that the impact of training may override the effect of sex-based physiological and anthropometric differences in the performance of kicking in soccer. The technical skill of creating a tension arc may allow female athletes to generate as much power in their kicks as novices males can through their physical size and strength. This challenges the stereotype that differences in power stem solely from differences in physicality. As such, skill level could play a greater role in differentiating kicking biomechanics and outcomes in athletes than sex-based differences.

2.6.5 Kicking Accuracy

There was a distinct lack of emphasis placed upon kicking accuracy in the studies included in this review. Only four studies explicitly stated that kicks must be on target to count as valid trials (Gheidi & Sadeghi, 2010; Navandar et al., 2017; Navandar et al., 2018; Sakamoto et al., 2013; Shan et al., 2012). Only one study investigated the differences in biomechanics between successful and unsuccessful kicks in male and female athletes, suggesting a trade-off between speed and accuracy (Gheidi & Sadeghi, 2010). While ball velocity was not reported by the authors, joint velocity values indicate that accurate kicks were performed with slower velocities than inaccurate ones. Instep kicks are more powerful and less accurate than inside kicks, which are used for precise passing (Teixeira, 1999). It is interesting to note that while female soccer players use instep kicks more frequently during open play, they tend to shoot on goal from a closer range using inside kicks (Althoff et al., 2010). This may be an effort by female athletes to increase their likelihood of converting goal scoring opportunities despite their lower ball velocities. Kicking accuracy may highlight further sex-based differences when comparing the execution of this skill.

2.6.6 Limitations

There are a number of limitations to this review. Only soccer and indoor soccer could be reported on, due to the dearth of research investigating kicking biomechanics in both sexes in other sports. As a result, the findings of this systematic review can only be applied to soccer, despite our protocol and search strategy originally aiming to include all field-based sports. It remains unclear how female and male kicking biomechanics compare in other games; this highlights the need for greater investment of time and resources into research in women's sport across the board.

The main findings of this review are mostly related to kinematics. Due to a lack of reporting in the included studies, kicking kinetics are not discussed in detail. Further research exploring the mechanical underpinnings of kicking differences between males and females is required to accurately compare the performance of this skill in the sexes. This evidence would have practical implications in terms of coach education and skill development. Given the paucity of research in this area, the authors deemed it useful to synthesis the available data in this review to inform further study.

The majority of studies in this review were found to be of moderate to low quality, mainly attributed to methodological shortcomings. There was significant heterogeneity between the included studies in relation to the definition and reporting of variables. This limited the authors' ability to perform meta-analyses and comprehensively present results. Duplicate publication bias was a risk for this review as two researchers conducted ten of the studies included. A number of these featured the same participants, with the same demographic information and some of the same results. Attempts to contact the author for further information on these studies were unsuccessful. To avoid double reporting of data in this review, studies that produced the same results with the same author were included only once.

This systematic review was undertaken to collate the current research on kicking biomechanics in male and female field-based athletes. The original purpose was to explore kicking biomechanics in field-based sports and their association with athletic hip and groin health. During initial search and screening phases, it became clear that this aim was too narrow, and the focus of the review was adjusted to a more relevant scope. This may have introduced a risk of bias as the authors were aware of relevant papers that could be included prior to the study selection stage.

2.6.7 Interpretations and Recommendations for Future Research

Based on the findings of this review, there a number of actionable areas that could be targeted in training for female athletes to improve kicking outcomes. Increased ankle plantarflexion, stability, and control could be achieved through strength, proprioceptive, and coordination training (Katis et al., 2015). Kicking practice with a focus on proximal-to-distal sequencing and foot-to-ball contact could enhance the quality of tension arcs formed by female athletes, increase the force generated, and improve the efficiency of energy transfer to the ball (Shan et al., 2019). Coaches should also be aware of the greater approach and trunk flexion angles exhibited by female players before, during, and after the kick, and consider how these can be factored into training drills (Shan, 2009; Shan et al., 2019). Further research comparing the kinetics of kicking in the sexes is needed to definitively inform training and coaching recommendations.

Anthropometric and physiological sex-based variations are well-researched and imply a physical advantage for males compared to females. The differences in force production and resulting ball and joint velocities between male and female athletes are therefore unsurprising. This may hold important implications for sporting regulations and competition conditions. At present, the fundamental components of the game of soccer are based entirely on data collected from men; all equipment and regulations are scaled to male specifications without consideration to female athletes (Andersen et al., 2012). Pitch dimensions, goal size, and match duration are factors which may contribute to differences in playing styles between male and female soccer players (Althoff et al., 2010). A number of sports have adapted competitive equipment to account for the differences between the sexes. Sports such as handball, cricket, basketball, volleyball, Gaelic football, and Australian rules football have introduced smaller balls, and even rule changes, for female athletes compared to those used by males (Andersen et al., 2016; International Basketball Federation, 2020; International Football Association Board, 2018; International Handball Federation, 2018). The use of a smaller ball in women's soccer was investigated by Andersen and colleagues; in an under-18 cohort, ball velocity increased by 4% and lower-limb muscular rate of perceived exertion was significantly lower (Andersen et al., 2012), while high level adult female athletes produced 6% faster kicks with the new ball size (Andersen et al., 2016). Further investigation would be of interest to establish how the use of a smaller ball could influence some of the differences between the sexes that have been identified in this review.

A key finding of this review is the lack of comparative research between male and female kicking athletes across the spectrum of field-based sports. Only soccer and indoor soccer could be included in this systematic review as a result of the paucity of data in this area. A significant effort is needed across the spectrum of sports biomechanics research to redress the balance of gender equality and support the rapid development of women's sport through timely, appropriate study.

2.7 Conclusion

Male soccer players produce significantly higher ball velocities than females, owing to variations in anthropometric and physiological characteristics, quality of tension arc creation, and efficiency of proximal-to-distal energy transfer in the kicking leg, which may increase their capacity to produce power. Females exhibit greater trunk flexion range of motion than males, as well as decreased ankle plantarflexion and distal joint velocities. Skill level within sex may play a more important role in kicking performance than differences between the sexes. Further research is needed to explore how female athletes kick across the spectrum of sports and how this varies from their male counterparts.

CHAPTER 3:

DEVELOPING A STUDY PROTOCOL TO INVESTIGATE KICKING BIOMECHANICS AND HIP AND GROIN HEALTH IN MALE AND FEMALE RUGBY PLAYERS

3.1 Study Justification

As outlined in the introduction to this thesis, women's rugby is one of the fastest growing sports in the world, with rapid increases in participation in recent years. Women and girls now represent more than a quarter of the global playing population (World Rugby, 2018). Despite this, there is a dearth of research into this sport, and how it compares to men's rugby. Rugby laws are the same for both sexes, but there are differences in the men's and women's games, which are determined by sex. As well as the physical and biomechanical differences between sexes, there is variation in technical skill, experience, and coaching. This manifests itself in many aspects of the game, one such being the area of kicking. This is an important skill in the modern game, yet there remains a perception that kicking in women's rugby is poor. The technical, biomechanical, and psychological reasoning behind this is not well understood. The goal of this project was to investigate the kinematics of kicking in women's rugby and compare it to the crop of research exploring this skill in the men's game. The research team also hoped to evaluate the prevalence of injury, common risk factors, and relationship between hip and groin health and kicking in female rugby players

3.2 Implications of the Covid-19 Pandemic

This Masters by Research began in September 2019, with an intended completion date of September 2019. The initial stages of the systematic review process were completed, and a study protocol was designed to investigate the kicking biomechanics and hip and groin health of male and female rugby players. Testing was scheduled to take place in March 2020; however, this could not be carried out due to the onset of the global pandemic in the same month. As a result of government restrictions and the following lockdowns, assessments for this research project could not be conducted for a number of months in 2020. I made significant efforts during this period to adapt the original protocol to allow testing to be carried out in a safe, feasible manner. However, due to the strict restrictions in place on sport, outdoor activities, and travel in the early lockdowns, no testing could be conducted in accordance with public health guidelines. Several iterations of the research protocol were created, with contingency plans created to account for all possible developments in the Covid-19 situation. Due to the widespread changes made to the initial testing procedure, a number of ethics applications and amendments were required during the course of this project. Following an extended period of limitation, testing was carried out in May 2021. The final testing protocol included different participants, testing locations, battery of tests and equipment compared to the original design. Comprehensive Covid-19 precautions, including risk assessments, full personal protective equipment, temperature checks, and vaccinations were necessary to facilitate the completion of this project. The sample size for testing was smaller than previously intended; as a result, this project is defined as a pilot study, designed to inform future research in this area.

3.3 Protocol Development and Adaptation

The original testing protocol created for this research project was adapted many times throughout the course of the global pandemic. Each iteration was developed fully, to ensure that testing could be carried out at any time, should restrictions be lifted. Overall, I designed a total of four protocols. These are outlined in full in the following sections.

3.3.1 Protocol 1

3.3.1.1 Aims and objectives

The original protocol for this research project was developed between September 2019 and March 2020. It was designed to address the gap in the literature regarding the biomechanics of kicking in women's rugby.

Its aims and objectives were as follows:

Aim: To investigate the hip and groin health and kicking kinematics of female rugby players, compared to their male counterparts.

Objectives:

1. To assess the subjective and objective hip and groin health of 20 female and 20 male rugby players performing kicking duties in the Women's All Ireland League (AIL), Women's Leinster League Division 1, Men's AIL Division 1A or Men's AIL Division 1B
2. To analyse the kicking kinematics of male and female rugby players performing kicking duties in the above-mentioned leagues.
3. To compare the hip and groin health of female rugby players to their male counterparts.
4. To compare the kicking kinematics of female rugby players to their male counterparts and identify any technical or biomechanical differences in performance that may be determined by sex.

Research Questions

1. Is hip and groin pathology common in high performing male and female rugby kickers?
2. Does kicking contribute to hip and groin pathology in this population?
3. What are the common kicking kinematics of male and female rugby kickers?
4. How do the kicking kinematics of female rugby players compare to those of their male counterparts?

3.3.1.2 Study Design

This study was designed to achieve the above aims and objectives. The original protocol consisted of two parts: a clinical component, assessing subjective and objective hip and groin health; and a field-based component, examining kicking techniques and outcomes. An ethics application was submitted to the Trinity College Dublin Faculty of Health Sciences Research Ethics Committee and a low risk assessment screening tool was completed for the study on the recommendation of the Deputy Data Protection Officer (Appendix 15). Ethical approval was received on 16/01/2020 (Appendix 16). The research proposal was submitted to Irish Rugby Football Union (IRFU) Sports Medicine Committee, who granted permission to recruit participants from IRFU-affiliated rugby clubs (Appendix 17). The research team consisted of colleagues from the Disciplines of Physiotherapy and Mechanical and Manufacturing Engineering in Trinity College Dublin, as well as rugby advisors and analysis experts from Leinster Rugby and the Irish Rugby Football Union (IRFU) (Table 4).

Table 4. Protocol 1 Research Team

Title and Name	Occupation	Research Position
Ms Molly Boyne	Masters by Research in Physiotherapy Student, Trinity College Dublin	Lead Investigator
Ms Alexandra Horgan	Chartered Physiotherapist	Co-Investigator and Simi Technology Advisor
Mr Emmet Farrell	Kicking Coach and Head Analyst, Leinster Rugby	Co-Investigator and Kicking Advisor
Mr Garreth Farrell	Head Physiotherapist, Leinster Rugby	Co-Investigator
Dr Ciaran Simms	Associate Professor of Mechanical and Manufacturing Engineering, Trinity College Dublin	Co-Investigator and Engineering Advisor
Dr Fiona Wilson	Associate Professor of Physiotherapy, Trinity College Dublin	Supervisor and Principal Investigator

3.3.1.3 Study Population

Given that most studies researching kicking kinematics in field-based sports feature high performing or elite athletes, it was deemed necessary to recruit participants from a similar performance level, to allow for appropriate comparison to the literature. As such, 20 female and 20 male rugby players were to be recruited from clubs competing in the highest domestic leagues for both sexes in Ireland during the 2019/2020 season; the Women's All Ireland League (AIL), Women's Leinster League (LL) Division 1, Men's AIL Division 1A and Men's AIL Division 1B. The eligible clubs across the four leagues are listed in Table 5 below.

Table 5. Protocol 1 Participant Recruitment Pool

Eligible women's teams		Eligible men's teams	
AIL	**LL Division 1**	**AIL Division 1A**	**AIL Division 1B**
Railway Union RFC	Railway Union RFC	Cork Constitution RFC	Highfield RFC
Old Belvedere RFC	Old Belvedere RFC	UCD RFC	Old Belvedere RFC
Blackrock College RFC	Wicklow RFC	Terenure College RFC	Old Wesley RFC
UL Bohemians RFC	Tullow RFC	Garryowen RFC	Malone RFC
Suttonians RFC	Edenderry RFC	UCC RFC	St Mary's College RFC
Cooke RFC	CYM RFC	Young Munster RFC	Shannon RFC
Malone RFC	Tullamore RFC	Clontarf RFC	Banbridge RFC
Galwegians RFC	DCU RFC	Dublin University RFC	City of Armagh
		Lansdowne RFC	Naas RFC
		Ballynahinch RFC	Navan RFC

3.3.1.4 Recruitment

To recruit participants as per this protocol, I would contact senior club officers in each club via email (Appendix 18). Details for these officers were to be accessed via the Leinster Rugby Domestic and IRFU websites. The club official in question would be asked to be a gatekeeper for the project and act as point of contact between the research team and their club members. They would be asked to forward a study information email to relevant teams in their club (Appendix 19), detailing the aims of the project, inclusion and exclusion criteria, methodology, benefits, and risks. The study's participant information leaflet (PIL) and consent form would be attached to this email.

Athletes who received the recruitment email from their club's gatekeeper would be deemed eligible to participate in the study based on a set of inclusion and exclusion criteria (Table 6). Interested candidates would have been invited to contact the research team via email or telephone for further information.

Table 6. Protocol 1 Participant Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
- Female and male rugby players - Aged 18 years and over - Competing in the Women's All Ireland League (AIL), Women's Leinster League Division 1, Men's AIL Division 1A or Men's AIL Division 1B - Performed kicking duties in at least two competitive fixtures in the 2017/18 and/or 2018/19 season	- Players not competing in the aforementioned leagues - Players with an ongoing acute or chronic time-loss injury - Players who have not performed kicking duties in competitive fixtures during the 2017/18 or 2018/19 season

3.3.1.5 Testing Location

Testing for this protocol would take place in the IRFU High Performance Centre on the Sport Ireland Campus, Snugsborough Road, Deanestown, Dublin. This facility is home to the Ireland National Men's, Women's and under 20's 15s teams, and the Men's and Women's 7s squads. It is designed to meet the training and recovery needs of these athletes and thus, is well equipped to facilitate the execution of this research study. The clinical hip and groin assessment would be carried out in the medical and rehabilitation area of the centre. This room is set up to offer privacy and comfort to athletes during examination. The gym would be used for further HAG testing (Figure 10).

The kicking assessment would be conducted on the HPC's indoor pitch (Figure 11). This 4G, flood lit half-pitch is perfectly suited to this testing protocol as it allows athletes to perform their kick trials in an authentic environment while eliminating lighting issues and wind variability.

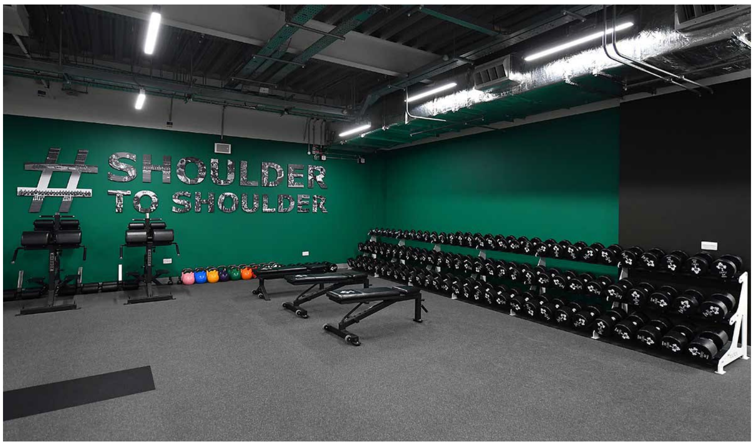


Figure 10. IRFU HPC gym. Photo by Seb Daly/Sportsfile.
Source: https://extra.ie/2019/12/24/sport/rugby/lenihan-why-irelands-new-base-will-boost-the-team.

Figure 11. IRFU HPC indoor 4G pitch. Photo by Seb Daly/Sportsfile.
Source: https://extra.ie/2019/12/24/sport/rugby/lenihan-why-irelands-new-base-will-boost-

3.3.1.6 Assessment Process

Eligible participants would have received a copy of the PIL and consent form at least seven days prior to their testing appointment. They would then be asked to attend the IRFU HPC on one occasion for their assessment. The session would last approximately 80 minutes and consist of two main components:

1. Hip and groin health examination
2. Kicking analysis

Before commencing the testing battery, participants would be briefed on the procedure and equipment involved in the assessments. They would be given the opportunity to seek clarification and ask any questions, after which they would sign an informed consent form, if they agree with all aspects of the study process. Participants would be asked a number of demographic questions including their age, injury history, rugby competitive level, years playing, kicking experience, and coaching history.

3.3.1.6.1 Hip and Groin Health Examination

Hip and groin health in participants would be assessed both qualitatively and quantitatively. Testing would consist of three components:

a. The Hip and Groin Outcome Score Questionnaire
b. Range of motion testing
c. Strength assessments

Hip and Groin Outcome Score Questionnaire

Following the initial introduction to the study, the hip and groin component of testing would begin. The subjective assessment would consist of the Hip and Groin Outcome Score

Questionnaire (HAGOS) (Appendix 20). This has seven sections and asks participants to rate their hip and groin health and how it has affected their daily life in the past week. Each question should be answered with a tick in the most appropriate box. If the player has not experienced the symptom referenced in a particular question, they should be instructed to give their best guess as to which response is the most accurate. The participant in question may have no hip or groin pathology but they would be asked to complete the questionnaire regardless.

Range of Motion Testing

I would perform the hip range of motion assessment in the Medical and Rehabilitation Area. Both lower limbs would be assessed, with the non-dominant leg measured first. Instructions would be provided to participants throughout. Participants' hip range of motion in all planes would be tested using a 12-inch goniometer (Figure 12). The two-arm goniometer is the most commonly used, economical and portable device for the evaluation of ROM (Lea and Gerhardt 1995). The Bent Knee Fall Out Test would be used to measure combined hip flexion, abduction, and external rotation. This is performed in a crook lying position and is measured using a tape measure. Full details of testing positions and procedures can be found in Appendix 21.

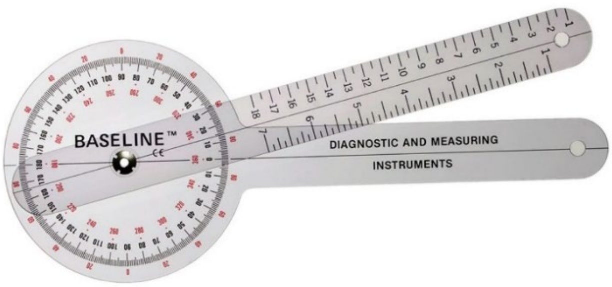


Figure 12. 12-inch manual goniometer.
Source: https://www.habdirect.co.uk/product/goniometer-12-inch/

Strength Assessments

Participants' hip strength would be assessed using the ForceFrame Strength Testing System (Vald Performance, Australia)(Figure 13). This is a fast, modular, portable, and repeatable system for isometric training, and testing strength and imbalance in hip, knee, shoulder, ankle, and neck-muscle groups. The device consists of a series of force cells attached to a metal frame, linked to a software application on my laptop, which would be used to store and analyse data. The force cells and the bars they are attached to are moveable, meaning participants can be tested in a variety of positions for a number of muscle tests. Athletes would be instructed to push as hard as they can against the force cells for a period of three seconds. This would be repeated three times, with a 30 second rest between repetitions. This process would be repeated for each testing position, with instructions provided to participants throughout. The ForceFrame would be set up in the HPC gym.

Figure 13. ForceFrame Strength Assessment System. Source: Vald Performance: https://valdperformance.com/forceframe/

Participants' hamstring strength would be assessed using the NordBord Hamstring Testing System (Vald Performance, Australia)(Figure 14). This is a fast, easy, accurate and reliable system for monitoring hamstring strength and imbalance. The device measures 3 feet long and 2 feet wide and consists of a padded board for participants to kneel on, as well as padded ankle hooks. The pad

Figure 14. NordBord Hamstring Assessment System. Source: Vald Performance: https://valdperformance.com/nordbord/

has integrated kneel position guides that allows for standardisation of testing. The ankle hooks are connected to 2 force cells which measure the force at which they are pulled. This data is transmitted via USB cable to software applications which collect and analyse data.

The NordBord would be set up in the High-Performance Gym beside the ForceFrame. Following the hip strength testing, participants would be briefed on the assessment protocol of the NordBord. They would be instructed to perform maximal Nordic Hamstring exercises on the NordBord, lowering themselves to the ground in as slow and controlled a manner as possible. They would perform three efforts, with 30 seconds rest between each repetition. Full details of testing positions and procedures for the strength assessments can be found in Appendix 21.

3.3.1.6.2 Kicking Assessment

The kicking kinematics of male and female rugby players would be recorded and analysed using high speed videography and motion capture technology. A high-speed camera would be used to record each phase of the kick to allow accurate movement analysis, joint angle measurement and comparison of kinematics. Simi Reality Motion technology would be used to provide real-time analysis of kicking with automated angle measurements.
The kicking assessment would take place on the indoor pitch adjacent to the gym in the HPC. Participants would be asked to wear shorts and rugby boots for this portion of session. Athletes will be instructed to perform a standardised 15-minute warm-up, including five minutes of self-directed, non-recorded kicking practice.

Following the warmup, the motion capture technology will be explained to the participants. The Simi Aktisys is a 2D dynamic movement analysis system (Figure 15). It consists of five LED markers, a high-speed video camera, and laptop, equipped with software which uses the markers to calculate measurements directly from the live stream of the camera (Figure 16). The system provides direct biofeedback and immediate movement data such as angles, distances, and axes, and the recorded videos can be viewed in play-back mode to allow further analysis.

Figure 15. Simi Aktisys System and LED markers. Source: Simi Reality Motion Systems

The LED markers would be attached to participants at the landmarks described below, using adhesive stickers and tape:

<u>Frontal view</u>

- Sternal notch
- Bilateral ASIS
- Bisect distal thigh of kicking leg
- Bisect leg at distal tibia of kicking leg

<u>Sagittal view</u>

- Lateral neck on kicking side
- Greater trochanter of kicking leg
- Lateral condyle of knee of kicking leg
- An inch below lateral malleolus of kicking leg
- Base of 5th metatarsal on kicking leg

Figure 16. Simi Aktisys marker attachment and camera. Source: Simi Reality Motion Systems

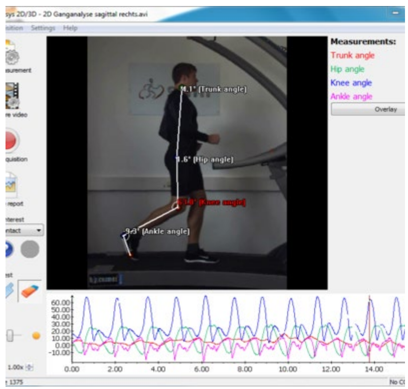


Figure 17. Simi Aktisys software. Source: Simi Reality Motion Systems

The Simi Aktisys camera would be positioned perpendicular to the target of the goal posts, in line with the kicking tee. Two further high-speed cameras would be positioned facing the athlete, one anteriorly and one posteriorly. Players were to be instructed to place their tee at three specified locations. They would be assessed in three types of kick: place kick, drop kick and punt kick. They were to perform two of each kick at the three sites, with a total number of 18 kicks to be completed. The first of each kick would be analysed from a perpendicular angle and the second would be assessed from an anterior position. Following this testing, there would be a 10-minute cool down and rest period.

3.3.1.7 Barriers to proposed protocol

3.3.1.7.1 Simi Motion Capture System

I carried out practice testing with a volunteer in the IRFU HPC in March 2020. This session was conducted so that I could become familiar with the testing equipment and environment and to trouble shoot any potential issues prior to official testing. The main portion of the practice testing was spent trialling the Simi Aktisys equipment on the indoor pitch, as a number of challenges arose with this system:

1. The laptop linked with the Simi software is several years old with poor battery life, requiring it to remain charging during use. While the indoor pitch has electrical sockets located at intervals in the surrounding walls, this limited the portability of the system.
2. The Simi high-speed camera is linked to the laptop via a series of wires, which further reduced the range of movement of the system.
3. The walls and roof enclosing the indoor pitch are glass (Figure 11). As a result, the environment is bright from the natural light outside and its reflection inside. The Simi system is extremely sensitive to light, as it relies on the different colours of the LED markers to detect joint movement. The brightness of the indoor pitch limited the

software's ability to identity and differentiate between the LEDs and thus could not track the motion of the athlete during the test kicks. I trialled a number of set-up variations, including adding and reducing light on the pitch, varying the brightness of the video footage, and increasing the colour contrast of the LEDs; all to minimal effect.

Following this trial session, I contacted Simi technical support, who advised that the system may not be ideally suited for this environment. I then began exploring other potential options for motion capture as part of this study.

3.3.1.7.2 Covid-19 Pandemic

Shortly after the practice testing session in the IRFU HPC, the World Health Organisation declared the Covid-19 crisis as a pandemic. Following this, the government implemented a series of strict restrictions on travel and indoor gatherings. The IRFU HPC closed to all for an extended period and when it reopened, only staff and players could access the site. As a result, we could not proceed with Protocol 1. The testing procedure was adapted over a period of months and Protocol 2 was developed in an attempt to continue with testing when it was safe to do so.

3.3.2 Protocol 2

3.3.2.1 Study Overview

During the early stages of lockdown, there was significant uncertainty regarding the length and severity of restrictions going forward. As such, I sought to adapt the original protocol to allow for all outcomes. Definitive research planning was difficult, and pragmatism was required. As a result, a number of protocols were developed at the same time and remained fluid as the health crisis unfolded.

Protocol 2 was created with the aim of minimising travel and indoor activity for participants. The aims and objectives of the research remained the same, with the same cohort of players recruited through their respective club officers as per Protocol 1. The main adaptations to this procedure relate to the location of testing and the equipment used to investigate kicking biomechanics. Covid-19 research practice guidelines, as set out by Trinity College Dublin, were defined, and plans for social distancing, hygiene etiquette, and personal protective equipment were established. These are described in detail in Chapter 4. An amendment to the original ethics application was submitted to the Trinity College Dublin Faculty of Health Sciences Research Ethics Committee. The research team was expanded to include Dr Nicol Van Dyk (NVD), IRFU Injury Surveillance and Research Medical Officer, and Mr Ross Norman (RN), Masters by Research Student in Biomechanical Engineering. RN's research project was designed to validate pose estimation software, OpenPose, using wearable sensors in the form of electrogoniometers.

3.3.2.2 Testing Location

To account for travel restrictions and reduce the onus on participants around the country to attend a central testing location, Protocol 2 defined the research venues as the sports ground of participating clubs. Per this procedure, the research team would travel to said clubs and conduct assessments with eligible players on their club grounds. The email to club officers was adapted to include a request for permission to use club facilities for this purpose as part of the recruitment process. Where possible, testing would be carried out on each club's training days to prevent unnecessary travel, limit interclub contacts, and facilitate participation. The clinical component of the protocol would take place in the club's medical room or a designated first aid room. Where access to the club house was restricted, a testing zone would be set up beside the club's main pitch. The kicking assessment would be carried out on this pitch.

3.3.2.3 Assessment

3.3.2.3.1 Hip and Groin Health Examination

The procedure for hip and groin health testing in this protocol is the same as Protocol 1, save for the assessment location. This would be specific to each club, depending on whether the research team could gain access to the club house. Where this was granted, the hip and groin assessments would be carried out in the medical room or a suitable changing room. If said facilities were unavailable, a testing gazebo would be set up on the side-line of the pitch, in the half furthest from the entrance to the club (Figure 18). All testing equipment would be set up inside, including the NordBord and ForceFrame units. Both devices are fully portable and would be used on loan from Leinster Rugby and the IRFU HPC respectively during the testing period.

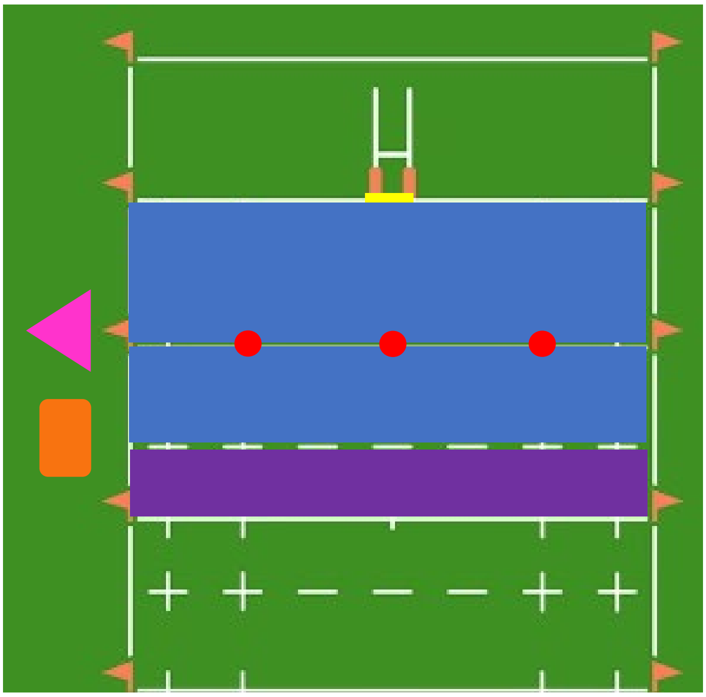


Figure 18. Protocol 2 testing zone set-up

Figure 18 key

- Kicking assessment zone
- Warm-up and cool down area
- Dugouts
- Testing gazebo
- Place kick trial locations
- Kick trial target

3.3.2.3.2 Kicking assessment

Equipment

As a result of the barriers identified to Protocol 1, a number of adaptations were made to the kicking assessment procedure. Due to the outdoor testing environment and limited portability of the Simi System, alternative methods of recording lower limb kicking biomechanics were devised. Three GoPro cameras were sourced through colleagues in the Department of Mechanical and Manufacturing Engineering; they would be used to collect video footage from each kicking trial from three different angles. They would be mounted on tripods and arranged in a triangle formation around the kicker during the trial. Three engineering members of the research team would manage the set-up of the cameras to ensure the correct dimensions were recorded. They would be calibrated using a checkerboard and synchronised used an iPad application. Electrogoniometers would be used to measure dynamic joint movement of the kicking leg in multiple plans. The procedure for use of these devices is described fully in Chapter 4.

Trial Procedure

The kicking assessment would take place outdoors on the club's main pitch and follow the same format as outline in Protocol 1. Participants would be instructed to wear shorts and rugby boots for testing. They would be guided by a member of the research team through a standardised warm-up before being given time for self-directed activation and unstructured kicking practice.

Athletes would be briefed on the testing procedure and the electrogoniometers and GoPros set-up. Participants would then be asked to perform high velocity, accurate place kicks towards the goal posts from three locations on the pitch. Through discussion with kicking coaches and analysts in Leinster Rugby, it was decided that only place kicks would be assessed as they were the most easily standardised. Kick trials would be taken from the 22m line at three intervals: 15m to the left of the posts, between the posts and 15m to the right of the posts respectively (Figure 19).

This distance was chosen to ensure that kicking efforts would be within all athlete's capabilities; thus, likely to reproduce their general kicking technique and unlikely to cause injury. The varying location were selected as easily standardised points across a pitch which do not require measurement and will create an accuracy challenge.

Participants would complete three kicks from each location, with the success of each kick documented. Athletes would use their own kicking tee or a generic one supplied by the research team. Three Gilbert Guinness Pro-14 balls would be used. Once the player has completed their three kicks at a given location, they will move to the next one, allowing time for the equipment to be rearranged.

When all nine trials have been completed, the participants would be guided in a cool down to prevent stiffness and soreness after the kicking and strength assessments.

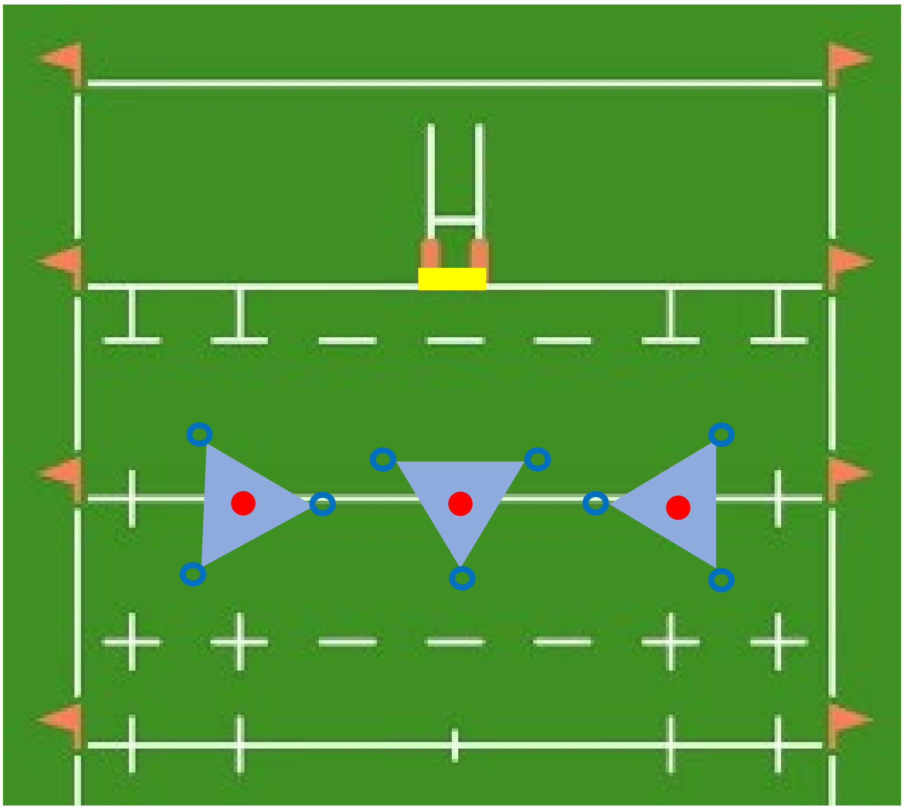


Figure 19. Protocol 2 pitch set-up

Figure 19 key

- Kick trial locations (red circle)
  - 15m left
  - Centre
  - 15m right
- Hypothetical camera locations (blue ring)
- Camera set-up space (blue triangle)
- Kick trial target (yellow bar)

3.3.2.4 Barriers to Proposed Protocol

Protocol 2 was designed to account for issues arising with equipment and government restrictions in Protocol 1. The testing location was changed from the central location of the IRFU HPC in Blanchardstown in Dublin, to prevent unnecessary travel for participants during the lockdown periods. It was the intention of the research team to move from club to club, testing eligible athletes on their own club grounds. However, given that the recruitment pool of teams competing in the All Ireland and Leinster Leagues remained unchanged from Protocol 1, this would require researchers to travel to all four provinces. At the time of development of Protocol 2, it was anticipated that restrictions on intercounty travel would not be in situ for an extended period and that sporting activities in small numbers would be allowed following a severe lockdown. However, as the global health crisis progressed, the IRFU announced that all amateur rugby matches were to be cancelled, domestic leagues suspended, and club grounds closed indefinitely (Irish Rugby Football Union, 2020a). This meant that testing with the original cohort was no longer feasible. Protocol 3 was created in response to this change, to facilitate any testing that could be safe carried out with high performance rugby athletes of a similar calibre to the initial sample.

3.3.3 Protocol 3

3.3.3.1 Study Overview

As the global health crisis unfolded in the first six months of 2020, the uncertainty regarding restrictions on social interaction, travel, and sporting activity persisted. The research team remained pragmatic and realistic regarding testing opportunities during this period. In July 2020, the IRFU announced the development of a one-off season plan for the 2020/21 season (Irish Rugby Football Union, 2020b). This included the creation of a new competition format for teams competing in the Energia AIL: the Energia Community Series (ECS). This would divide the league into four conferences based on the provinces, with clubs only competing against opposition from within their own conference. The teams competing in each province and their fixtures were released in July and August 2020 for the men's and women's competitions respectively. Protocol 3 was developed by adapting the recruitment population and strategy to account for this updated competition structure and the resulting changes to the testing locations. All other aspects of the testing procedure were the same as previous iterations, with no changes to the assessment methods from Protocol 2.

An ethics amendment was submitted to the Trinity College Dublin Faculty of Health Sciences Research Ethics Committee, detailing the updates to the testing procedure. This was rejected on the grounds that the protocol had changed too significantly from the original form. A new ethics application was created, detailing a number of possible testing scenarios that could be implemented depending on the level of restrictions in place. A Data Protection Impact Assessment (DPIA) was completed and submitted to the Deputy DPO. Both were approved, with the research classed as low risk.

3.3.3.2 Study Population

As part of Protocol 3, participants would be recruited from teams competing in the Men's and Women's Energia Community Series Leinster Conferences (Table 7). This conference was selected as it was the closest to the research team and had the most teams participating across both competitions. Only one conference was included as part of the recruitment strategy to prevent unnecessary travel and avoid interactions between the provincial bubbles.

Table 7. Protocol 3 Participant Recruitment Pool

Energia Community Series	
Women's teams	**Men's teams**
Railway Union RFC	Lansdowne RFC
Old Belvedere RFC	UCD RFC
Blackrock College RFC	Terenure College RFC
Suttonians RFC	Dublin University RFC
Wicklow RFC	Clontarf RFC
	Naas RFC
	Old Belvedere RFC
	Old Wesley RFC
	St Mary's College RFC

Players would be recruited as per the previous protocols: via emails sent to their respective club officers. The inclusion criteria for the study were adapted to account for the difference in league structure and the time elapsed since athletes had last performed kicking duties in a competitive fixture; these are listed in Table 8.

Table 8. Protocol 3 Participant Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
- Female and male rugby players - Aged 18 years and over - Competing in the Women's or Men's Energia Community Series Leinster Conference - Actively performing kicking duties for their team during competitive fixtures	- Players not competing in the aforementioned leagues - Players with an ongoing acute or chronic time-loss injury - Players who do not fulfil a kicking role for their team during competitive fixtures

3.3.3.3 Testing Location

As per Protocol 2, the primary location for data collection would be the sportsgrounds of the clubs from which participants will be recruited. With the permission of the clubs, testing locations would include:

- Railway Union RFC, Railway Union Sports Club, Park Avenue, Sandymount, Dublin 4.
- Old Belvedere RFC, Ailesbury Grove, Ballsbridge, Dublin 4.
- Lansdowne RFC, Lansdowne Road, Dublin 4.
- Old Wesley RFC, Donnybrook, Dublin 4.
- UCD RFC, University College Dublin, Belfield, Dublin 4.
- Dublin University RFC, Trinity College Dublin, College Green, Dublin 2.
- Terenure College RFC, Greenlea Grove, Terenure, Dublin 6.
- St. Mary's College RFC, Templeville Road, Templeogue, Dublin 6.

- Suttonians RFC, Station Road, Sutton, Dublin 13.
- Blackrock College RFC, Stradbrook Road, Mountashton, Blackrock, Co. Dublin.
- Wicklow RFC, Ashtown Lane, Ashtown, Wicklow Town, Co. Wicklow.
- Naas RFC, Forenaughts, Naas, Co. Kildare.

3.3.3.4 Pilot Testing

Two rounds of pilot testing for the kicking portion of this protocol were carried out: both in December 2020. The purpose of these sessions was to give the research team the opportunity to practice their methods and trouble shoot any potential issues before official testing. Data from the pilot testing was inspected informally to confirm its relative accuracy, but it was not analysed in depth.

On 9th December 2020, a consenting volunteer (an elite female rugby kicker with international experience) was invited to Railway Union RFC in Sandymount, Dublin 4, on one occasion to undergo a kicking assessment (Figure 20). Four members of the research team were present: MB, FW, CS, and RN. The kick testing was completed as per the protocol above. Kicking kinematics were recorded using electrogoniometers and three GoPro Hero cameras. The cameras were calibrated using a checkerboard.

Figure 20. Pilot testing of Protocol 3 in Railway Union RFC on 9th December 2020

On 17th December, FW and I carried out an informal testing session to practice the application and use of the electrogoniometers during the kicking assessment. A consenting male volunteer with experience of kicking at school-boy level participated in a kicking trial in Bushy Park, Terenure, Dublin 6. Kicking kinematics were recorded using electrogoniometers, with no kicking footage collected on this occasion.

Figure 21. Pilot testing of Protocol 3 in Bushy Park on 17th December 2020

3.3.3.5 Barriers to the Proposed Protocol

Protocol 3 was developed in response to the cancellation of the 2019/20 AIL season by the IRFU in March 2020. The creation of a new competitive structure in the form of the ECS was a positive step towards the return of rugby. However, the research team encountered a number of delays in commencing testing during this period.

There was an extended period of uncertainty regarding a return to training for AIL teams during summer 2020, as only elite teams were granted permission to resume training. This status was allocated to a number of high-level amateur sports such as Gaelic games, but only professional or international rugby teams were classed as elite. As a result, athletes eligible for inclusion in this study were not involved in full training until late August/early September 2020. The research team could not avail of their club grounds for testing during this period due to restricted access.

Researchers were also conscious that players in these teams may not have the facilities or opportunity to practice kicking while in lockdown. We believed that testing athletes before they were reintroduced to training would affect the accuracy of our results and increase their risk of injury. As such, the research team deemed it necessary to wait for training to resume for the eligible teams.

During this period, I had access to two ankle and one hip twin-axis electrogoniometers. Practice testing was carried out with these devices in order to validate them against a manual goniometer. It was noted at this time that the electrogoniometer for the hip joint was damaged from previous research and was no longer accurately reporting kinematic data. The Principal Investigator contacted Biometrics Ltd in June 2020 to request advice regarding repair and to enquire about the purchase of a knee sensor. Due to staffing shortages during the pandemic, a response was not received from the company until late July. A returns authorisation form and quotation were provided in mid-August. Upon return, technicians in Biometrics Ltd stated that the SG150B could not be repaired; as such, a new SG150B hip sensor and SG150 knee sensor were purchased at the same time in September. In early October, the research team were informed of a production issue with the SG150B device. This delayed shipping for a further four weeks, during which period no pilot or official trials could be conducted.

On 14th October 2020, the IRFU announced the suspension of the Energia Community Series, as domestic rugby was removed from the exemption list for training and matches under Level 3 and 4 restrictions (O'Connor, 2020). The competition was dissolved, rendering our new recruitment strategy obsolete. The arrival of the Biometrics Ltd equipment in mid-November was too late to begin testing with this cohort. The IRFU 2020/21 Season Plan aimed for the return of the full AIL competitive structure in 2021; however, on 28th January 2021, the IRFU issued a statement declaring the cancellation of the AIL for the 2020/21 season (Irish Rugby Football Union, 2021). Given that Protocol 3 was developed to account for the changes associated with the introduction of the Energia Series, the continuation of this procedure was no longer justified at this juncture.

With no testing equipment available to the research team before November 2020 and no teams competing after this date, a fourth protocol was created to provide the greatest possible opportunity to carry out testing with rugby players in 2021. One strand of this protocol was completed as part of this project; the process of which is outlined in Chapter 4.

CHAPTER 4:

EXPLORING THE KICKING KINEMATICS OF ELITE FEMALE RUGBY PLAYERS

4.1 Introduction

4.1.1 Study Background

Following the easing of government restrictions over the Christmas period in 2020, Level 5 measures were reintroduced at the end of December 2020 (Department of the Taoiseach, 2020). Strict limitations were placed on travel, social gatherings, and non-essential retail. These measures remained in place until 12th April 2021 (Department of the Taoiseach, 2021). Restrictions on amateur sport continued until 10th May 2021, when pods of 15 players could return to training. This extended period of lockdown was extremely limiting for the research team in terms of their ability to carry out any testing. The previous protocol iterations remained as potential options, however, due to time pressure on the Lead Researcher to complete her studies, researchers deemed it necessary to take a different recruitment tact. This chapter outlines the process of developing and testing the resulting protocol.

At the end of April 2021, Dr Nicol Van Dyk (NVD) entered discussions with IRFU management regarding the possibility of conducting the project with members of the national 15s and 7s teams. As elite athletes in a strictly controlled bubble, these players had been training consistently for the duration of lockdown. Following a brief exchange, this request was accepted, pending changes to the original protocol and adherence to a number of Covid-19 procedures. Pragmatism and compromise were required to ensure that this opportunity could be seized. An amended protocol was developed rapidly, as the window of availability of players and facilities was very narrow. Access to the HPC was only granted for 5th May 2021. Squads available for testing at this time were the Ireland Women's 15s and 7s teams; the research team made the decision to proceed with this cohort and adapted the research plan accordingly.

4.1.2 Design

This study was designed based on previous protocols and adapted to suit the available facilities and participants. Following the initial contact made with Ireland squad management by NVD, I began designing an amended study protocol, based on the previous iterations, and adapted to suit the available facilities and participants. A comprehensive document was created and submitted to the IRFU Sports Medicine Committee, IRFU Covid-19 Committee, and IRFU HPC management; this detailed the background, purpose, methods, Covid-19 precautions, and projected outcomes for participants. The protocol was accepted and permission to carry out testing with athletes from the Women's XVs and 7s squads in the IRFU was granted.

4.1.3 Aims and Objectives

Given the restrictions on the testing procedures (that a limited number of players of only one gender were available during the time of testing and that the research team were restricted in their ability to carry out their original testing battery), the aims of previous protocol iterations were no longer appropriate. Comparison of male and female athletes was not possible as only one gender of players was available at the time of testing. Attempting to characterise women's kicking in rugby based on a small convenience sample size would have been inappropriate and misleading, particularly considering that this is the first study of its kind in this area. As such, the researchers adapted the aims and objectives of this trial as a pilot test for the protocol, with a view to carrying out a more robust study in the future.

The amended aims and objectives are as follows:

Aim: to develop and evaluate a study protocol designed to explore the kicking kinematics of elite female rugby players.

Objectives:

1. Develop and adapt a research protocol to explore kicking kinematics in elite female rugby players.
2. Test the protocol by carrying out kicking assessments with elite Women's 15s and 7s players using electrogoniometers in the IRFU HPC.
3. Analyse the results of the kicking assessments using Biometrics Ltd software to provide insight into the kicking kinematics of these players during drop and place kicks.
4. Compare kinematic data to demographic and performance variables to identify possible associations.
5. Evaluate the efficacy of the testing procedure in providing relevant, accurate data on the kicking kinematics of female rugby players.
6. Make recommendations for future iterations of the protocol and further study in this area based on the outcome of the testing pilot.

4.2 Methodology

4.2.1 Study Population

Participants for this study were female rugby players recruited from the Ireland 15s and 7s Rugby programmes. These squads consist of elite athletes who have continued to train throughout the pandemic as part of the IRFU High Performance bubble. They follow strict Covid-19 protocols and are closely monitored by management and clinical staff. They are well placed to participate in this study as they are suitably trained, conditioned, and safe to be involved in testing which will be carried out on site within their training bubble.

Male players from the same programmes were not available for inclusion during this period: The Men's 15s team were completing the final stages of the 2021 Six Nations competition; the Men's u20s were preparing to enter camp ahead of their Six Nations campaign; and the Men's 7s team were in focussed training for the upcoming Tokyo Olympics 2020.

4.2.2 Recruitment

Participants were recruited through the IRFU; specifically, the National Women's Medical Coordinator and Head Physiotherapist, Joanne Montgomery (JM). She was the point of contact for the research team, who advised on best practice for recruitment, testing protocols, and Covid-19 procedures. JM acted as the gatekeeper for the project, liaising with the IRFU Covid-19 Committee, HPC management, and the national teams. She identified players eligible to be included in the study based on the inclusion criteria outlined in Table 9. Players involved with the Ireland Women's XVs and 7s squads received recruitment information at the discretion of the programme management. This included a participant information leaflet (Appendix 22) and consent form (Appendix 23), with details on the aims of the research, inclusion and exclusion criteria, methodology, and benefits and risks of involvement. Athletes were advised of the voluntary nature of the study and could contact the research team at any time with queries. Those interested in participating contacted JM, who formulated a testing schedule for players.

Table 9. Protocol 4 Participant Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
- Elite rugby players involved with the Ireland Women's 15s or 7s Programmes - Aged 18 years and over - Actively involved in training with their respective national squads - Experienced in place and/or drop kicking at an elite/national level	- Players aged under 18 years old - With a current acute or chronic time-loss injury - Not actively training with their respective national squad - No experience of place or drop kicking at an elite/national level - Otherwise deemed ineligible to partake in this study by the research team or programme management

4.2.3 Testing Location

Testing was carried out on the indoor pitch in the IRFU HPC. This site was only available to researchers on 5th May 2021, with the next free date falling in July. This was due to squad scheduling across the different elite teams using the facilities. Team infection prevention control pods were strictly maintained, with no cross over allowed between the various national teams. This day was the only one where the site was only being used by the Women's 15s and 7s teams. Following this, the Men's 7s teams would be entering to begin their focussed training for the Tokyo Olympics 2020 and the Men's u20 would begin their preparation for the u20s Six Nations. As such, the research team deemed it necessary to adapt the protocol as necessary to ensure that testing could be carried out.

Researchers were given access to the indoor pitch but could not use the gym or its equipment for Covid-19 protocol reasons; as such, it was not feasible for the hip and groin assessments to be carried. The NordBord and ForceFrame in the HPC itself were not available at the time of testing; the research team were unable to source alternative devices from Vald Performance due to the time constraints on use of the HPC. Thus, the kicking assessment formed the sole focus of the testing.

4.2.4 Covid-19 Precautions

Testing was carried out in accordance with Covid-19 precautions and procedures outlined by the IRFU for its high performance centres and those specified by the Sport Ireland site. Research practice guidelines were adhered to throughout the project process, as set out in the Trinity College Dublin School of Medicine's "Policies and procedures to minimise risk of Covid-19 to staff, students and patients" document and "Resumption of direct human testing in scientific research" draft operating procedures. Social distancing, hygiene etiquette, and appropriate personal protective equipment were used by both the research team and participants at all times during testing.

4.2.4.1 Risk Stratification

The various components of this research were stratified into high, moderate, and low risk of transmitting Covid-19 based on the "Resumption of direct human testing in scientific research" document developed by Trinity College Dublin School of Medicine. Activities undertaken as part of this project fall into the moderate and low risk activity categories.

4.2.4.1.1 Moderate Risk Activities

The attachment of electrogoniometers for the kicking assessment was deemed to be moderate risk due to unavoidable human-to-human contact. This involves the palpation of bony landmarks, the preparation of skin for sensor attachment, and the placement of the devices in situ. The removal of the electrogoniometers also requires close proximity between the researcher and participant. At all times, both parties wore appropriate PPE and practice good hand hygiene to negate this risk.

4.2.4.1.2 Low Risk Activities

All other components of testing, including pre-test screening, warm-up, and cooldown, and kicking assessment were designated as low risk activities due to the limited direct human-to-human contact.

- Pre-test screening forms were completed online and returned to the research team prior to the assessment session.
- Warm-ups and cooldowns were guided by a member of the research team from a distance of 2m.
- Once the kicking recording devices were attached to the participants, the kicking assessment could be performed with the researchers at a safe social distance from the kicker. All equipment was sanitised after every use.

4.2.4.2 Risk Management

To reduce the risks of Covid-19 transmission identified above, the following risk management strategies were adhered to:

- Only two fully vaccinated members of the research team were granted permission to access the HPC.
- Both researchers had a PCR test 48 hours prior to entering the HPC and provided proof of a ‘not detected’ result to JM 24 hours in advance.
- Researchers completed an IRFU Covid-19 education course on Gainline, the IRFU’s online portal, and read the HPC-specific guidelines.

- All athletes and researchers underwent pre-trial screening before entering the HPC, including a Covid-19 symptom declaration form, risk assessment, and temperature check.
- Appropriate PPE was used by the researchers and participants through the testing process:
    - Researchers wore medical face masks for the duration of testing. They wore goggles and disposable plastic aprons when in direct contact with participants.
    - Participants wore medical face masks while the testing equipment was set up and when in close proximity to the researchers. They were permitted to remove their mask if they wished during their kicking trials.
- Hand sanitisation with hand gel was completed upon arrival, after contact with any surface, and upon departure from the testing site.
- Social distancing was observed whenever possible.
- All non-reusable test equipment was disposed of after us in appropriately labelled biohazard bin bags upon completion of activities.
- All reusable test equipment and surfaces were disinfected after use.

4.2.5 Assessment

4.2.5.1 PIL, Consent Form, and Demographic Questionnaire

Those eligible and interested in participating in this project received the PIL and consent form seven days prior to the testing date. They were asked to read both carefully and contact the research team with any queries. If they agreed to each aspect of the study, they were asked to initial and sign the consent form. The day prior to testing, participating athletes received a demographic questionnaire to be completed and returned to the researchers, along with their consent form. This questionnaire collected personal data (age, height, weight), as well as information on their playing career, kicking experience, and injury history (Appendix 24).

4.2.5.2 Participant Arrival

Participants were scheduled hourly on the day of testing to prevent interaction between athletes. They were temperature checked on arrival to the IRFU HPC and were greeted by me. The premise of the study was briefly explained, and the player was given the opportunity to ask any questions they might have. I confirmed receipt of their consent form; if the participant was happy to continue, they were introduced to the testing equipment.

4.2.5.3 Testing Equipment

4.2.5.3.1 Electrogoniometers

Lower limb biomechanics during kicking were recorded using electrogoniometers. An electrogoniometer is an electronic device that uses angle sensors, such as potentiometers, strain gauges and, accelerometers to measure dynamic joint movement in multiple planes. These devices are lightweight, flexible, and portable for use in field testing (Bronner, Agraharasamakulam, & Ojofeitimi, 2010b). Electrogoniometers have a high reliability and validity when compared to a digital protractor and motion analysis system (Bronner, Agraharasamakulam, & Ojofeitimi, 2010a; Bronner et al., 2010b; Piriyaprasarth, Morris, Winter, & Bialocerkowski, 2008) and have been used extensively across biomechanical research in sport and injury management (Chow, Yam, Chung, & Fong, 2017; Lotfian, Cherati, Jamshidi, & Sanjari, 2014; Moradi, Rajabi, Minoonejad, & Aghaei, 2014; Thibordeeand & Prasartwuth, 2014). A set of electrogoniometers were provided to the research team by the Discipline of Physiotherapy in Trinity College Dublin, having been used to good effect as part of a previous study carried out by the Principal Investigator. Given their reputability and availability, the research team opted to use these devices as a replacement for the original Simi Motion Capture System. Informal testing was carried out with the electrogoniometers to validate their outputs against a manual goniometer in a simple range of motion test; results for the electrogoniometers were comparable to the handheld goniometer and deemed suitable for use before official testing commenced.

Three twin-axis Electrogoniometers (Biometrics Ltd) were used to record joint kinematics during the movement assessments (Figure 22). The sensors were attached to the lateral aspect of each participant’s ankle, knee, and hip. The twin-axis ankle electrogoniometer (SG110/A) measured ankle dorsiflexion/plantarflexion and inversion/eversion. The twin-axis knee electrogoniometer (SG150) recorded flexion/extension and valgus/varus movements. The SG150B is traditionally a spinal sensor; however, upon recommendation from a contact at Biometrics Ltd, this was used at the hip to measure range of flexion/extension and abduction/adduction. The data collected by these sensors was recorded on the Biometrics Ltd DataLog recording device (Figure 23) and saved onto a micro SD card. The Electrogoniometers were connected to the DataLog device using two 500mm wires per device. These wires inputted into any one of eight channels on the DataLog which recorded the multiplane movement.

The recording channels for the kicking tests were as follows:

Channel 1: Ankle dorsiflexion/plantarflexion
Channel 2: Ankle inversion/eversion
Channel 3: Knee flexion/extension
Channel 4: Knee valgus/varus
Channel 5: Hip flexion/extension
Channel 6: Hip abduction/adduction

Figure 22. Biometrics electrogoniometers

Figure 23. Biometrics DataLog recording device

The electrogoniometers were attached to the participant's kicking leg using tape and bandages (Figure 17). Pre-wrap adhesive spray was be applied to the participant's skin to promote adhesion. Double-sided body tape was applied to the end blocks of the Electrogoniometers. The first end block was positioned on the skin below the joint first; approximately 80% stretch was applied to the spring wire between the end blocks by pulling the spring to its maximum length and releasing the stretch by roughly 1/5. The second end block was attached above the joint being measured, with the joint in a neutral position.

At the ankle joint, the inferior end block was attached to the lateral aspect of the participant's boot and the superior end block was positioned on the lateral leg in line with the lateral malleolus.

At the knee, the inferior end block was attached to the lateral aspect of the leg, below the head of the fibula. The superior end block was applied to the lateral aspect of the thigh, in line with the femur.

At the hip, the sensor had to be positioned under the athlete's shorts, with the central wire passing under the band of their underwear. The inferior block was applied to the lateral superior thigh in the region of the greater trochanter. The superior end block was attached to the lateral hip.

Once the sensors were applied, the participant was asked to move each joint through its full range to ensure that excessive stretch would not be applied to the wires during kicking. Once the researcher was happy with the positioning, they secured the end blocks with elastic adhesive bandages and anchored them with rigid tape.

Figure 24. Electrogoniometer testing set-up

The Electrogoniometers were set-up on the participants prior to the warm-up to ensure they remained in place for the duration of the assessment. Following this, the accompanying wires were be inserted into the Electrogoniometers and positioned under the player's clothes to attach to the DataLog device. This was be carried in a sports bag around their waist. The wires were be secured using elastic adhesive tape to keep them in place.

4.2.5.3.2 High-speed Camera

Previous protocol iterations involved the use of three GoPro Hero 8 cameras to record footage of the kicking assessments. These cameras were made available to the research team through the Department of Mechanical and Manufacturing Engineering in Trinity College Dublin. However, due to the short window between the approval of testing in the HPC and the data collection date, it was not possible to source this equipment. Only two members of the team (MB and FW) were given access to the HPC; this was not sufficient personnel to manage the cameras, the accompanying checkerboard and iPad, set-up the electrogoniometers, and guide the players through their assessment. As such, we made the executive decision to forgo the video recordings of the kicks in favour of robust electrogoniometer data collection. On the day of testing, a high-speed video camera from the IRFU Performance Analysis Department became available. We were given permission to use the camera, which was controlled by FW initially, and by me for the majority of the testing session. The camera was positioned at ~45 degrees to the kicker, between the goal posts and the kicking tee, or perpendicular to the goal post along the 22m line of the pitch.

Figure 25. Video camera set-up

4.2.5.4 Warm-up

Participants warmed up using an adapted version of the FIFA 11+ Warm-up Protocol, under my guidance (Appendix 25). This injury-prevention programme was developed in 2006 under the leadership of the FIFA Medical Assessment and Research Centre and in collaboration with the Oslo Sports Trauma Research Centre and the Santa Monica Orthopaedic and Sports Medicine

Centre. It was specifically designed to reduce the risk of injury in soccer players and has been found do so by 30% (Sadigursky et al., 2017). Given the nature of the assessment as a kicking-intensive session, it was deemed appropriate to complete a robust, validated football warm-up to ensure the athletes were prepared to perform. The warm-up was conducted between the 40 metre and half-way lines on the indoor pitch. Two parallel lines of five cones will be set up in the channel between the half-way and 10m lines, 5 metres apart (Figure 26). All running exercises will involve running between these cones.

The programme takes 20 minutes to complete and consists of:

1. Running exercises
2. Strength, plyometrics and balance exercises
3. Running exercises

The strength, plyometrics and balance exercise blocks have three different levels (1,2 or 3) increasing in difficulty, which can be selected or progressed to, depending on an athlete's ability. Given that the cohort of participants involved in this study were high performing athletes, Level 2 was selected to ensure the players were sufficiently prepared for their assessment.

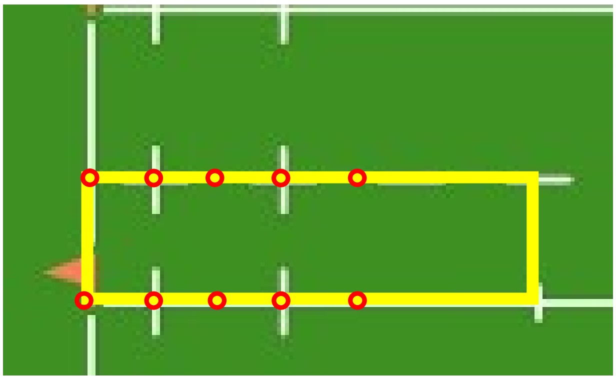


Figure 26. Warm-up zone set-up

Figure 26 key

Warm-up zone

Cones

Following the standardised warm-up and once the testing devices were set-up on the participants, they were given the opportunity to warm-up further. Therabands and balls were provided for self-directed activation and kicking practice. Any sensors or tape that came loose during this portion of the session were securely fastened to ensure they remained in place during the official tests.

Figure 27. Warm-up zone set-up with equipment

4.2.5.5 Kicking trials

Once the warm-up had been completed, the official kicking assessment began. Athletes were asked to perform a series of kicks towards the goal posts from three locations on the pitch (Figure 28). Players were given the option to perform place and/or drop kicks, depending on their experience with these kicking types in the different rugby codes. Through discussion with kicking coaches and analysts in Leinster Rugby, it was decided that kick trials would be taken from the 22m line towards the goal posts at three intervals. For place kicks, these locations were 15m to the left of the posts, between the posts and 15m to the right of the posts respectively. For drop kicks, players were asked to drop the ball on the 22m line in line with the left post, between the posts and in line with the right post. These locations were chosen to ensure that kicking efforts would be within all athlete’s capabilities; thus, likely to reproduce their general kicking technique and unlikely to cause injury. The varying locations were selected as easily standardised points across a pitch which do not require measurement and will create an accuracy challenge. Place kicks were performed by placing the ball on a kicking tee. Drop kicks were be performed from the hand; the ball was required to hit the ground before it is struck with the foot to count as a valid trial.

Participants completed three trials of each kick from each location, totalling nine of each kick type. Those who performed place and drop kicks completed 18 trials. Athletes carried out their kicks in any order they wished, using their own kicking tee. The success of their kicks was documented. Eight Gilbert Guinness Pro-14 balls were used: three training balls and five match day balls. The Electrogoniometers were zeroed with the player standing in a neutral position before testing began. I manually commenced recording on the DataLog device before the first kick at each location and ceased after the third kick had been completed. Once the player had completed their three kicks at a given location, they moved to the next one.

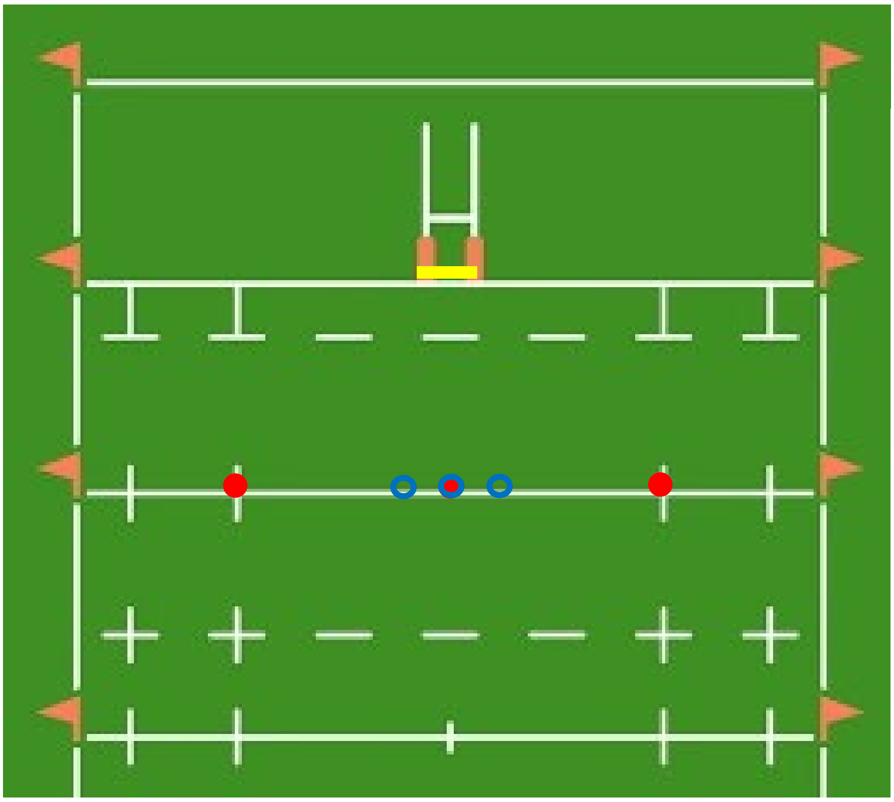


Figure 28. Pitch set-up for kicking assessment

Figure 28 key

Place kick trial locations on 22m line
- 15m left
- Centre
- 15m right

Drop kick trial locations
- In line with left post
- Centre
- In line with right post

Kick trial target

After the kicking test has been completed, participants were invited to perform a cool down to prevent stiffness and soreness after the kicking and strength assessments. An example of a cool down routine was provided to the participants, consisting of light aerobic exercise static stretches of the main lower limb (Appendix 26).

4.3 Data Management

4.3.1 Data Collection, Protection, and Storage

All data gathered as part of this research project had a purpose and was intended for use as part of the analysis of the kicking of women's rugby players. Personal data collected included participant names, contact details, and written consent. Sensitive data collected from participants included demographic information, electrogoniometer data, and video footage of the kicking assessment. All data will be handled in accordance with the current Data Protection Acts. FW and I, as the data processors for this study, completed the GDPR online training and associated quiz, as provided by Trinity College Dublin. I also completed a GDPR and Health-Related Research Training Workshop on 10/11/20. Discussions were held with the Deputy Data Protection Officer for Research, who recommended a low-risk screening assessment be carried out for this study, as part of the ethics application. This was completed and approved by the Data Protection Office in Trinity College Dublin.

The research team took all appropriate measures to ensure confidentiality for participants of this study and to secure the privacy of their data. To do so, athletes' identities were pseudonymised. The data collected from participants was identifiable immediately after it was recorded; however, all data was coded using identification numbers before being transferred from the testing site. This allowed for comparison of a single participant's data while protecting the confidentiality of said information. Only FW and I had access to the identification number codes. Other members of the research team had access to the pseudonymised data; namely, the engineering colleagues who were responsible for the management and analysis of the electrogoniometer data and were involved in the evaluation of the kicking footage. Data collected in this study was stored in a password-protected database on secured, encrypted laptops and computers. Transfer of data between investigators was carried out using secured emails of password-protected files and a secured, private Trinity College Dublin Microsoft Teams group. Portable devices and cloud transfers were required for data processing due to the restrictions on travel and access to research offices during the pandemic. All hard copy forms will be kept in a locked cabinet in the Physiotherapy Postgraduate Office in the Trinity Centre for Health Sciences.

4.3.2 Participant Consent

Participants were informed of what data was being collected, how it was being collected and why it was required in the PIL. This leaflet also explained the location and method of data collection, who would have access to their data, how it would be used, and the risks associated with storing and using this data. The PIL and consent form were provided to athletes seven days before their testing date. Participants were given the opportunity to clarify any parts of these documents, before giving their informed consent by signing the consent form if they agreed with each individual section. On the PIL, participants' rights under the General Data Protection Regulations (GDPR) were explained. Athletes were advised that if they wished to access their data to rectify, erase or move it, or to object to its processing, they could contact the researchers. Contact details for all members of the research team were provided on the PIL. For any participant who may have wished to file a complaint relating to this study, contact information for the Data Protection Commissioner was also listed.

4.4 Data Analysis

4.4.1 Data Collection Issues

Data collected as part of this study included demographic information, kinematic data from the electrogoniometers, and video footage from the high-speed camera. It was recorded with the aim of exploring the kicking biomechanics in female rugby athletes and evaluating the procedure by which this was carried out. From the electrogoniometer results, the research team hoped to gain insight into lower limb joint range of motion, linear joint velocity, angular velocity, acceleration, and displacement during kicks performed by female athletes. Issues arose with this aim upon review of the data collected. This data was analysed by engineering colleagues on the research team as the only members of the project group with the facility and capacity to run the Biometrics Ltd software. Upon examination of the electrogoniometer data, it was noted that a number of trial recordings across all participants had been distorted by a series of errors in the measurement of the kinematic data. This could not have been identified on the day of testing as the DataLog device does not offer the facility to view recordings. The errors in question varied from mild to significant and resulted in uncharacteristically large ranges of motion at each joint in the graphical representations of these kicks. Some graphs spiked from -180 to 180°, particularly at the ankle, and others showed the same results for movements in different planes, especially at the hip. These errors, typically referred to as noise, affected the majority of kick trial recordings and presented an issue for the research team in terms of the efficacy of the protocol.

4.4.1.1 Further Investigation

In order to investigate this further, researchers carried out a number of inspections of the electrogoniometers. All devices used in testing were examined visually: two ankle (SG110/A), one knee (SG150), and one hip sensor (SG150B). Moderate wear and tear to the hip device was noted; this electrogoniometer was exposed to considerable amount of movement during trials as it was positioned under each participants' shorts and attached to the lateral hip and thigh of their kicking leg. Manual, handheld testing was performed with the electrogoniometers. The devices were connected to the DataLog recording device and positioned on a flat surface. Researchers then moved the moving arm of the sensors in horizontal and vertical planes, while observing the screen of the DataLog. This provides a real-time display of the ranges of motion of the electrogoniometers. It was observed that all goniometers, with the exception of the SG150 knee device, were consistently showing results that did not reflect the movement of the sensors.

Further field testing was performed with the electrogoniometers to assess how they would perform under dynamic movement constraints. RN and I carried out an on-pitch testing session. During this, I donned the electrogoniometers and performed a series of drop and place kick trials; these efforts were videoed using a smart phone camera. Standing range of motion exercises were also performed at each joint, at both slow and fast pace in each plane. This was to examine how the electrogoniometer recordings differed between smooth, control movements and rapid, dynamic efforts. The data collected from these trial tests were analysed using the Biometrics software and once again indicated a high level of background noise across all sensors, most significantly at the ankle, and noticeable cross talk, particularly at the hip.

The research team compiled this trial testing data and contacted Biometrics Ltd for advice. No response was received; as such, the researchers endeavoured to establish ways to validate the results obtained during official testing, and other methods to calculate kicking kinematics based on the testing carried out.

4.4.2 Data Analysis Methods

4.4.2.1 Electrogoniometers

Electrogoniometer data was analysed in collaboration with engineering colleagues, particularly RN. The Biometrics Ltd software used to display and examine the collected data was stored on a CD ROM, and as such, only compatible with computers with a disk driver. Due to the restrictions on travel and gatherings during the Covid-19 pandemic, the CD ROM was kept in the possession of RN, as he had the facilities to download the data and run the software. Following the testing date, the SD card files from the Biometrics DataLog were securely downloaded onto my laptop. They were pseudonymised and labelled based on the participants' identification codes, the type of kick, and the location of the kick. These files were transferred to the RN via a private Microsoft Teams group and the data was subsequently uploaded to the Biometrics Analysis Software.

The results of the Biometrics software analysis were reviewed by MB and RN. For each participant, graphical representations of each recording were produced, each of which included three kicking trials from the given location. The timings of the kicks were compared to peaks and troughs in the range of motion curves to distinguish the three efforts. This was completed for both place and drop kicks. Angle plots were created for each location, with curves representing each joint (ankle, knee, hip) and plane (sagittal and coronal); these were presented both collectively and individually. Further analysis of joint curves was carried out on kicks from one location of each kick type per participant. These trials were selected based on the most suitable accompanying video footage to facilitate meaningful comparison.

Data from graphs was extracted to calculate joint angle ranges. The data analysis tools in the Biometrics software were not accurate enough to allow for joint angle determination from time intervals in the graphs. In order to achieve this, a programming and numeric computing platform, MATLAB, was used to examine the data. Biometrics files were converted to txt files for use in with MATLAB software. A MATLAB code was run on each kick and the joint angle history plotted for each recording (Figure 24A). The three kicks at each location were distinguished from each other on the graph using the knee flexion/extension angle (Figure 24B). This was identifiable on the original Biometrics plot, with a distinct peak and trough pattern. This was used to determine at what time point in the recording each kick occurred. The X axis coordinate found at the knee was then applied across the other joint ranges to identify maximum and minimum angles (Y axis) at that time point (Figure 24C). Each joint angle for each kick was exported to a Microsoft Excel file in order to calculate means and produce clear graphical representations of the results.

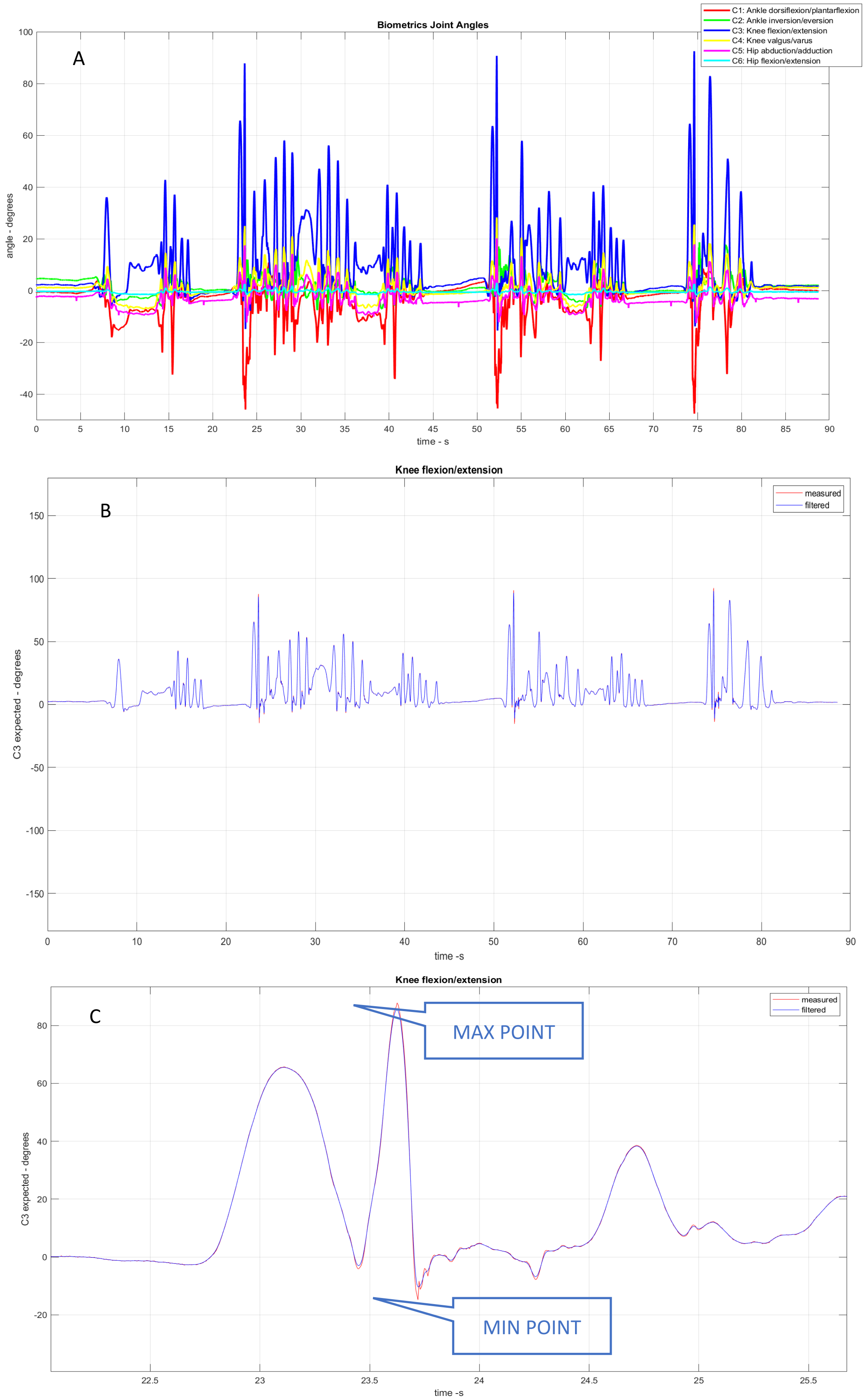


Figure 29. Example of MATLAB kick plot (Drop kick by Participant 2). **A.** All joint ankles for three trials. **B.** Knee flexion/extension angles for three trials. **C.** Knee flexion/extension minimum and maximum angles in one trial.

4.4.2.2 Filtering

Due the dynamic nature of kicking, the graphs of the kicks produced by the Biometrics Ltd software appeared to feature a high volume of background noise, which skewed the results. In an effort to reduce some of this distortion, a filtering process was undertaken. A series of Butterworth filters were applied to the data using MATLAB. The chosen frequencies were based on those applied in previous research using electrogoniometers: 5.5Hz (Bronner et al., 2010a, 2010b), 10Hz (Carnaz, Oliveira, Sato, Hansson, & Coury, 2008), 15Hz (Kondo, 2018) and 20Hz (Petushek et al., 2012). Due to the level of noise in the electrogoniometer files, the 20Hz filter was deemed most appropriate and applied across all kick trial recordings.

4.4.2.3 Video footage

The high-speed camera used to collect footage of the kicking trials was made available to the researchers by the IRFU. Upon request, these video files were shared with the research team via a secure Microsoft Teams transfer. The footage was reviewed by RN and I. Participants were identified and videos labelled as per the unique identifier codes for each athlete. Video footage was cropped several times for each kicker and each kick. This included a full-length clip of all three kicks from each location, an extended clip of each kick from ball placement to the end of follow-through, and a shortened version of each trial, from the point of initial movement towards the ball to the end of follow-through. The duration of each participant's kicks was noted, and a mean of each kick type calculated.

The shortened kick trial footage was then sliced at a rate of 30 frames per second. A frame-by-frame analysis was performed by two researchers (MB and RN) to identify key points in each kick. For place kicks, these were the point of initial movement towards the ball, peak kicking leg hip extension, peak knee flexion, the point of ball contact, and peak hip flexion. For drop kicks, these were peak hip extension, peak knee flexion, the point of ball contact, and peak hip flexion. These points were compared to the electrogoniometer plots to confirm timings for the graph curves. The duration of the kicks was calculated from the number of frames between the different time points (0.034 seconds per frame).

4.4.2.4 Qualitative Review

When the electrogoniometer results and video footage had been processed for analysis, the data was reviewed qualitatively by members of the research team. MB, RN, FW, and CS reviewed the joint range of motion angles recorded by the electrogoniometers and compared them to normative kicking ranges, as well as their knowledge of human movement patterns, as experienced physiotherapists and biomechanical engineers. The extended video clips of each kicking trial by the participants were examined by the same researchers. A single kick trial of each type from each athlete was selected for closer analysis and descriptive comparison to the electrogoniometer data; the kick with the most perpendicular video recording angle was chosen to allow the researchers to evaluate joint angles with 2D footage. Particular attention was paid to maximum hip extension, knee flexion, and hip flexion; these are key points during the kicking movement in the sagittal plane which could be identified in the 2D video recordings, still frames, and electrogoniometer graphs.

4.4.2.5 Manual 2D Analysis

Researchers estimated the joint angles of maximum hip extension, knee flexion, and hip flexion based on observation as part of the qualitative review. To enhance the robustness of this subjective method, an objective element was added to the process. The still frames of the key points from each kick from each participant were collated into a Microsoft PowerPoint file. A slide was created for each kick, containing images the peak ranges of the hip and knee. Limb orientations were mapped onto these frames using line drawing functions and the joint angles between the lines were identified by overlaying the limb lines on a protractor image (Figure 30). The researchers recognised the crude, 2D nature of this method; however, it provided a rough, objective measure of joint range of motion to accompany the observational estimates and compare to the electrogoniometer data.

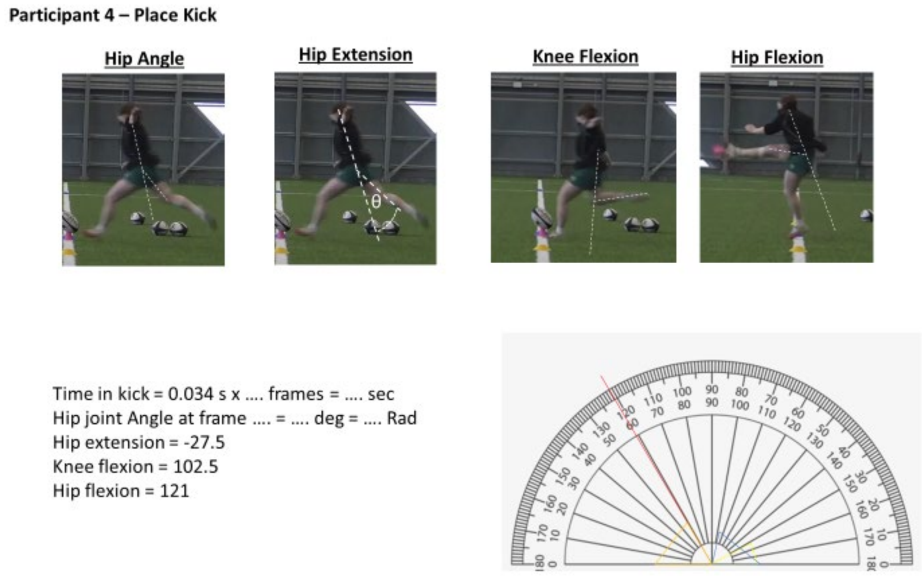


Figure 30. Manual 2D analysis method using PowerPoint and protractor example

4.4.2.6 Pose Estimation

Pose estimation is a computer vision technique that predicts and tracks the location of a person or object. This is achieved through examination of the pose and orientation of a given subject. OpenPose is a 2D pose estimation programme that can detect human body key points from single images (de Jonge-Hoekstra & Repgen, 2020). This software is in use and under investigation as part of many projects in the Department of Mechanical and Manufacturing Engineering in Trinity College Dublin, including the research conducted by RN. As part of his work, he has endeavoured to validate OpenPose by comparing it to other range of motion tracking methods, including electrogoniometric data, during these kick trials. This pose estimation programme was applied to some of the videos collected as part of this study. As a 2D software, OpenPose is only compatible with footage taken from a perpendicular angle. Place kick trials could be analysed using this method, as at least one kick from each participant was recorded at a suitable angle. The software could not be applied to drop kicks, due to a parallax error introduced by non-perpendicular angulation and the amount of rotation used by players to perform this kick type.

In the case of the place kick trials, a total of 24 nodes were mapped onto the face, body, and feet (Figure 31). Processed videos were then sliced into frames, to identify joint ranges of motion at the key points mentioned in 4.4.2.3 (Figure 32).

These were:

- Kicking leg hip angle, measured from the neck (node 1) to the hip (node 8) to the knee (node 10 or 13)
- Kicking leg knee angle, measured from the hip (node 8) to the knee (node 10 or 13) to the ankle (node 11 or 14)
- Angle between kicking leg and support leg, measured from one knee (node 10 or 13) to the hip (node 8) to the other knee. This angle was calculated out of interest by engineering colleagues to provide another comparative reference.

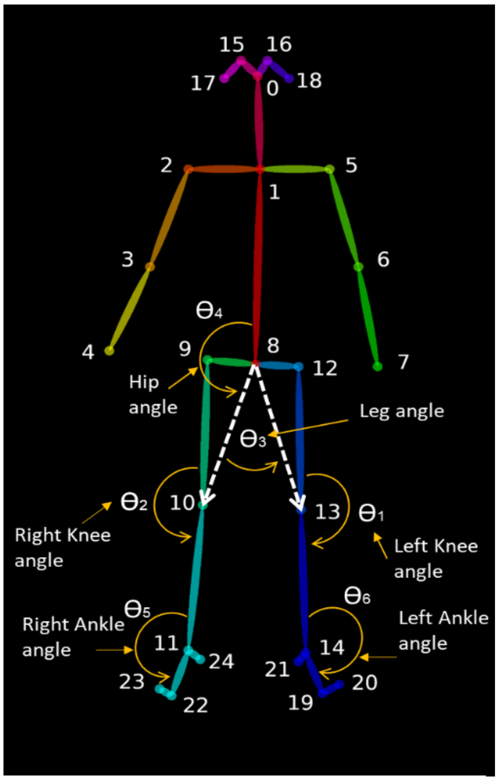


Figure 31. OpenPose node mapping example

Given that not all footage was recorded from a 45° angle, there were some minor issues with the angle overlay straying from the joint centre locations predicted by the OpenPose software. The angles reported by this programme were compared to those yielded by the electrogoniometers for mutual validation.

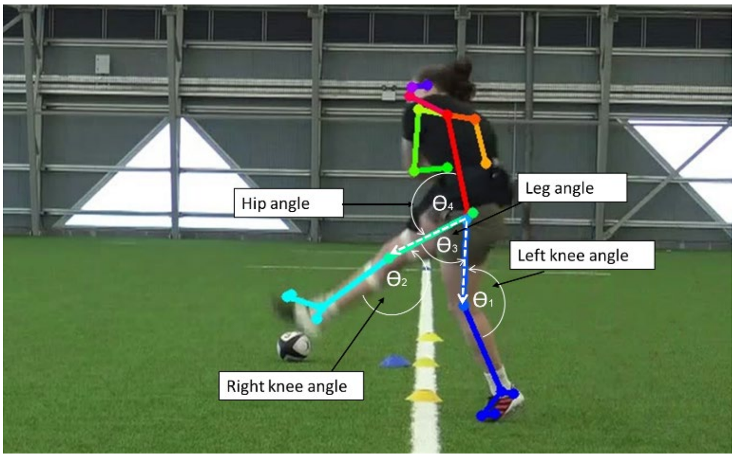


Figure 32. OpenPose key point mapping example

4.4.2.7 Demographic Information

Demographic information for this study was collected using a questionnaire. This data included age, injury history, rugby competitive level, years playing, kicking experience, and coaching history. This information was used to contextualise the kinematic results of the study and provide insight into the experience of elite female rugby players in Ireland.

4.4.3 Statistical Analysis

Descriptive statistical analyses were performed on the kinematic data collected during the kicking trials using Excel and GraphPad Prism. Mean and median values were calculated for the peak angles of each joint. An analysis of variance (ANOVA) was carried out to compare meaningful joint angular results obtained for the hip and knee during place kicks using the electrogoniometers, OpenPose software, and manual protractor method. T-tests were used to analyse the differences in joint ranges between the electrogoniometer and protractor methods during drop kicks.

CHAPTER 5:
Results

5.1 Participants

5.1.1 Demographic Information

Nine Ireland Women's Rugby players were recruited to take part in this study; three of whom are involved solely with the 15s programmes, three who play only 7s, and three who compete at an international standard in both codes. Participants ranged in age from 20 to 31 years old, with a mean age of 24.56 ± 4.19 years (Table 10). Athletes had a mean height of 170.33 ± 6.02cm and an average weight of 69.79 ± 6.29kg. All athletes were free from injury at the time of assessment and provided their full written consent to participate. Full details of participants' demographic information can be found in Table 11.

5.1.2 Playing Experience

Length of rugby playing experience varied from six to 13 years; the mean playing age for participants was 8.56 ± 2.6 years. Five athletes began their rugby careers at age grade level (aged six to 18); two at Minis Rugby (under 8s to under 12s) and three at Youth Rugby level (under 18s). Three participants joined a rugby club as an adult, while one player began playing in college. A number of players have been capped at underage provincial (n=5) and senior provincial (n=4) level. Four athletes represented Ireland on the under 18s 7s team. As well as their respective national teams, all athletes were associated with a club competing in the All Ireland League. Of the nine participants, eight reported playing or having played a sport other than rugby. Gaelic football was the most common of these (n=6), followed by Camogie (n=4) and soccer (n=3).

5.1.3 Kicking Experience

Of nine participants, seven were right footed kickers, with two left foot dominant athletes. Kicking experience ranged from three months to seven years. All athletes reported performing drop kicks;

seven participants also had experience with place and punt kicking, with only one player performing box kicks. Eight players reported having received kicking coaching at some point in their career. Of these, five were at an international standard, in the lead up to the 2021 Six Nations Championship or one-off sessions with national coaches. Four players completed sessions with their club or province, but none were described as frequent.

Table 10. Descriptive Analysis of Participant Information

Statistical analysis	Age (years)	Height (cm)	Weight (kg)	Playing age (years)
Range	20-31	162.5-180	62.5-79	6-13
Median	24	172	67	8
Mean	24.56	170.33	69.79	8.56
Standard deviation	4.19	6.02	6.29	2.60

Table 11. Participant Demographic Information

	General			Rugby					Kicking			
Player	Age (years)	Height (cm)	Weight (kg)	Rugby Code	Position	Years playing	Rugby history	Other sports	Kicking leg	Kicking experience	Type of kicks	Coaching for kicking
P1	27	162.5	63	7s	Outhalf	7	Played GAA for local club before being drafted to Ireland 7s.	Gaelic Football and Camogie for club and county	Right	7 years	Drop kicks	Yes – from Anthony Eddy (Director of 7s and Women's Rugby, IRFU), Adam Griggs (Women's Head Coach, Ireland XVs), and Richie Murphy (Head Coach, Ireland u20s)
P2	21	173	73	7s and 15s	Forward, centre, outhalf	13	Started at 8 years old. Played minis until youth rugby aged 12. Played youth rugby with local club. Moved to an AIL club at 14. Represented Leinster in 7s. Drafted to Ireland 7s set up at 16.	Karate aged 6-8	Right	U18s Leinster from 15 years old. Ireland 7s from 18 years old.	Drop kicks and place kicks	Yes – from multiple coaches across youth to adult rugby.
P3	20	172	62.6	7s	Centre, outhalf	8	Started at u15s with local club and played u18swith the same club. Played for Leinster u18s in 2017/2018 and 2018/2019, as well as Ireland u18 7s in 2018/2019.	N/A	Right	2 years	Drop kicks	No.

							Joined Ireland senior 7s squad summer of 2019. Joined university rugby club in 2019. Moved to AIL club in 2020. Current Ireland 7s player.					
P4	20	162.5	66.5	7s	Outhalf	7	Started in local club at 13. Played for Connacht u18sfor 3 years and Ireland u18s 7s for 2 years. Played for Connacht Seniors in 2019 Interpro Championship. Joined Ireland 7s programme in September 2020.	Camogie and Gaelic Football until 16 years old.	Right	4 years	Drop kicks, place kicks, punt kicks	Yes – coaching on place and punt kicking when playing with Connacht Seniors.
P5	24	172	73	7s and 15s	Outhalf	7	Started playing rugby in school. Picked for Ireland u18s 7s. Joined Ireland Senior 7s squad 6 years ago. Capped at XVs in 2021. Currently playing both XVs and 7s.	GAA from 8 years old until starting Senior 7s. Plays during off-season as permitted.	Left	Several years in 7s. Less than 3 months in XVs.	Drop kicks, place kicks, punt kicks	Yes – began kicking for 15s 2 months ago. Completed 1 hour coaching session with Adam Griggs per week in preparation for 2021 Six Nations.
P6	22	173	79	7s and 15s	Centre, outhalf, full back	13	Started playing mixed mini rugby in local club at 7 years old. Played for 5 years until too old to play with boys at u12s. Stopped playing for 2 years.	GAA from 5 years old until Summer 2019. Basketball in school and	Right	Since 2014/15	Drop kicks, place kicks, punt kicks	Yes – periodic 1-1 coaching sessions at club, provincial, and national levels during career; irregular and mostly informal.

							Joined another club and played u15, u18 and senior rugby from 2014-2018. Munster u18 2015-2017. Has played with the senior Munster squad since 2018. Played U18 Ireland 7s in 2016-2017. Played with Ireland XVs since October 2018.	represented county. Rowed competitively with coastal rowing club in summers at school. Golf recreationally.				Completed 1 hour coaching session with Adam Griggs per week in preparation for 2021 Six Nations.
P7	30	180	67	15s	Outhalf, wing, fullback	8	Started with local club in 2013. Joined Ireland 7s squad in 2014 and played until 2020. Member of Irish XVs 2015-present (on and off).	Gaelic Football at intercounty level and soccer in Women's National League.	Left	Several years	Drop kicks, place kicks, punt kicks	Yes – Completed 1 hour coaching session with Adam Griggs per week in preparation for 2021 Six Nations.
P8	31	174	78.5	15s	Number 8	6	Started with local club in 2015/16. Moved to AIL club in 2018/19.	Soccer, golf, volleyball.	Right	6 years	Drop kicks, place kicks, punt kicks	Yes – Small kicking sessions with Adam Griggs on a few occasions.
P9	26	164	65.5	15s	Outhalf, scrumhalf, fullback	8	Started playing in college. Playing history includes 3 AIL clubs, an English Premiership team, Munster, Leinster, and Ireland XVs.	Camogie, Gaelic Football, soccer.	Right	4 years	Drop kicks, place kicks, punt kicks, box kicks	Yes – Worked with a coach in English Premiership club and worked with Tony Yapp (Kicking Coach, School of Kicking) previously.

5.2 Kicking Assessment

5.2.1 Trials Completed

All nine participants completed the kicking assessment. Five athletes performed both place and drop kicks, while three players carried out only drop kicks. Participants who carried out kicking trials for both types completed a total of 18 kicks; those who performed drop kicks only took nine shots on goal. Median accuracy for drop kicks was 5/9 shots on target (56%). Median accuracy for place kicks was 6/9 (67%). Overall median accuracy for all kicks was 67%. Trial details and accuracy results are listed in Table 12.

Table 12. Kicking Trial Performance Results

Player	Kick Type		Accuracy																					
			Drop										Place											
	Place	Drop	Left			Centre			Right			Total	Left			Centre			Right			Total	Total	%
			1	2	3	1	2	3	1	2	3		1	2	3	1	2	3	1	2	3			
P1	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓	✗	7											7/9	78
P2	✗	✓	✓	✓	✗	✓	✓	✓	✗	✗	✓	6											6/9	67
P3	✗	✓	✗	✗	✗	✗	✓	✓	✗	✗	✗	2											2/9	22
P4	✓	✓	✗	✓	✗	✓	✓	✓	✓	✓	✓	7	✓	✓	✗	✓	✓	✓	✗	✓	✗	6	13/18	72
P5	✓	✓	✗	✓	✗	✓	✓	✗	✗	✓	✓	5	✓	✓	✗	✓	✓	✓	✓	✗	✗	6	11/18	61
P6	✓	✓	✗	✓	✗	✗	✗	✓	✓	✓		4	✗	✓	✗	✓	✓	✗	✗	✗	✗	3	7/18	39
P7	✓	✓	✗	✓	✗	✗	✓	✗	✓	✓	✓	5	✗	✗	✓	✓	✓	✓	✓	✓	✓	7	12/18	67
P8	✓	✓	✗	✗	✓	✗	✗	✗	✗	✗	✓	2	✓	✗	✓	✓	✓	✓	✗	✓	✗	6	8/18	44
P9	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	8	✗	✓	✓	✓	✓	✓	✓	✗	✓	8	16/18	89

5.2.2 Electrogoniometer Results

5.2.2.1 Electrogoniometer Graphs

The data obtained from the Biometrics software was analysed using MATLAB and Microsoft Excel. Range of motion curves for three kicks from one location of each kick type (drop kick and place kick) per participant are presented in Figure 33 and Figure 34 respectively. Plot curves sloping positively above 0° on the Y axis indicate a flexion/abduction/valgus motion, while negative values represent an extension/adduction/varus movement pattern. In the case of several participants, there was significant distortion to the data recorded using the ankle electrogoniometer, which rendered the remaining graphical data unreadable. Where this occurred, the ankle data plots were removed from the aforementioned figures for the purpose of the clear presentation of results. Such errors occurred across the spectrum of sensors for Participant 1; hence, the wide ranging values on the Y axis of their graph. The original MATLAB graphs containing the background noise can be found in Appendix 27.

Figure 33. Drop Kick Electrogoniometer Data, presented graphically using Microsoft Excel

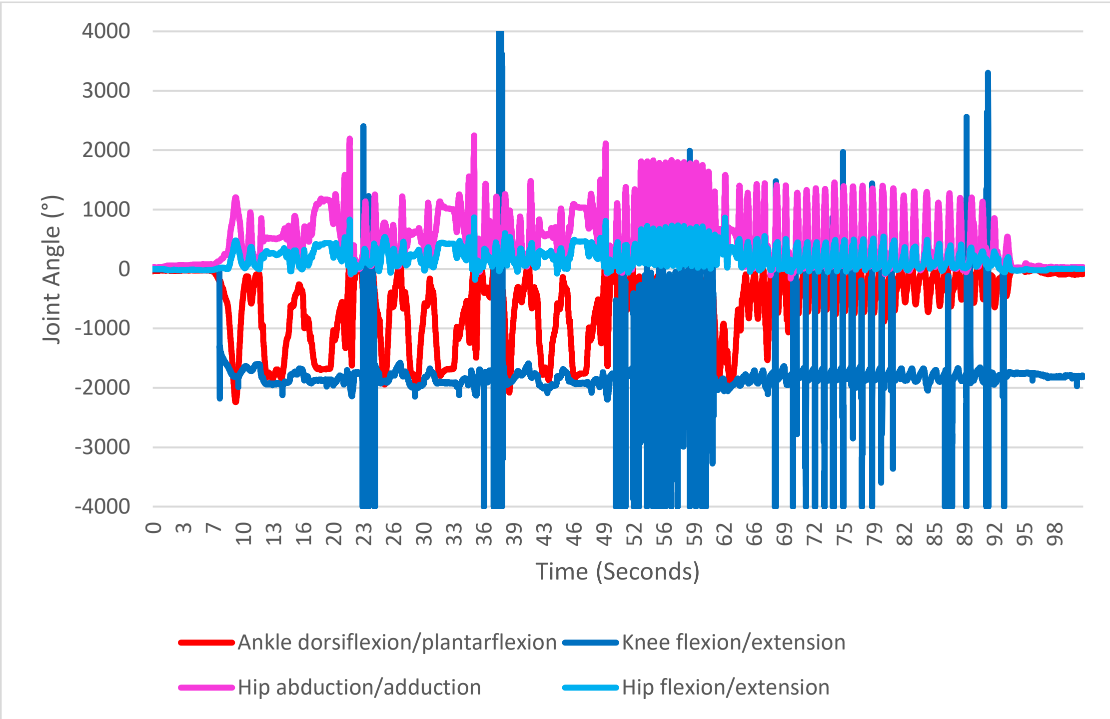


Figure 33A. Participant 1 – Drop Kick from the Right

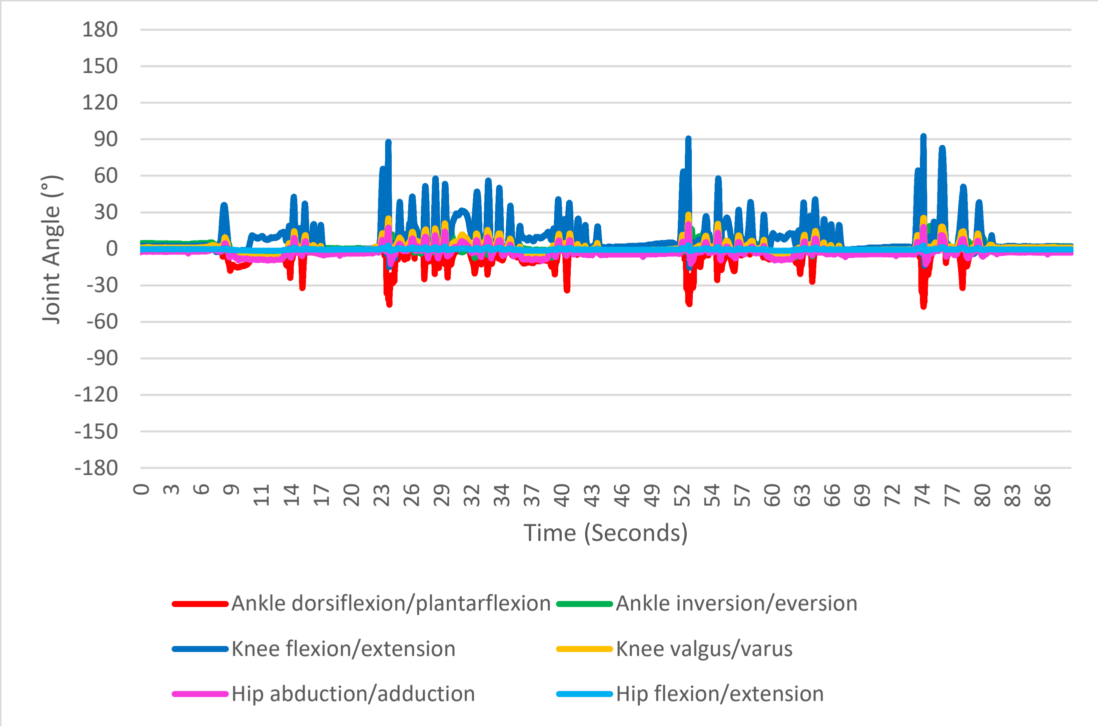


Figure 33B. Participant 2 – Drop Kick from the Centre

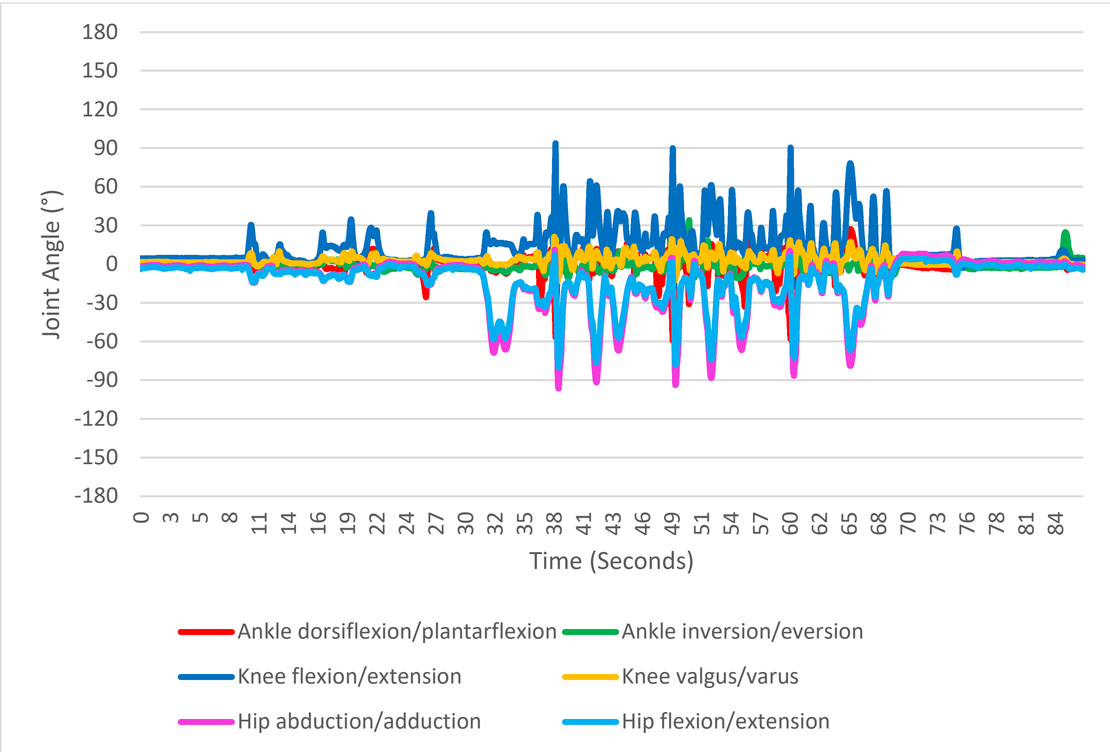


Figure 33C. Participant 3 – Drop Kick from the Centre

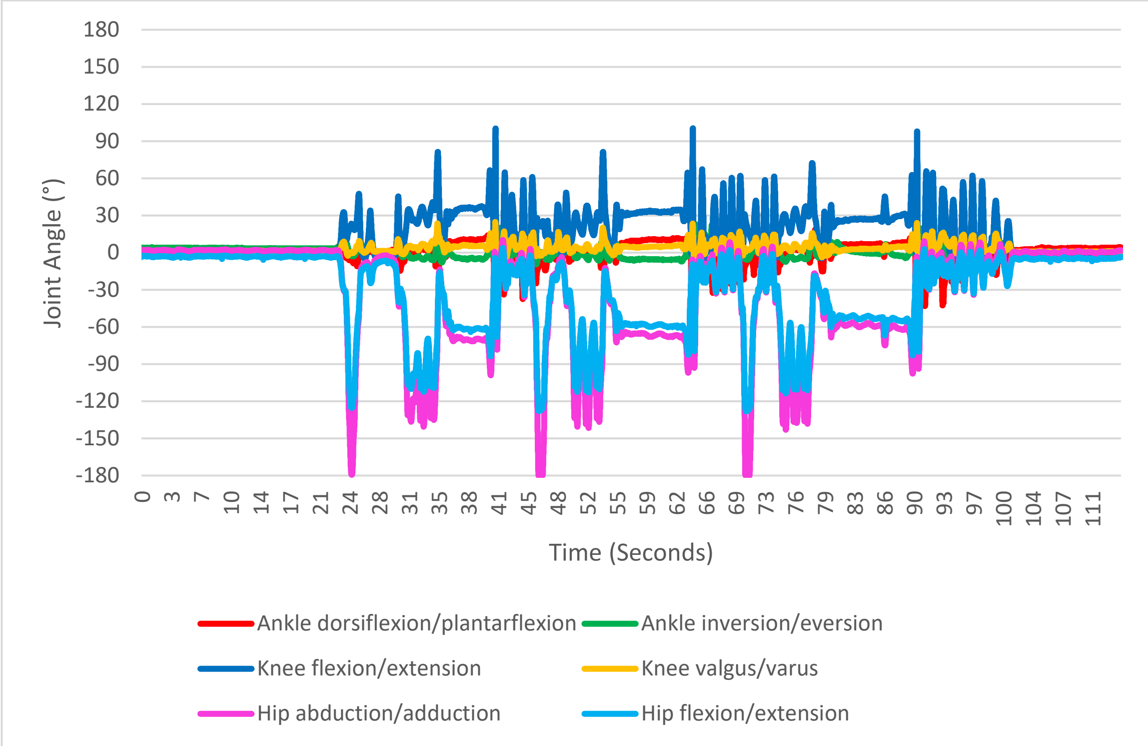


Figure 33D. Participant 4 – Drop Kick from the Centre

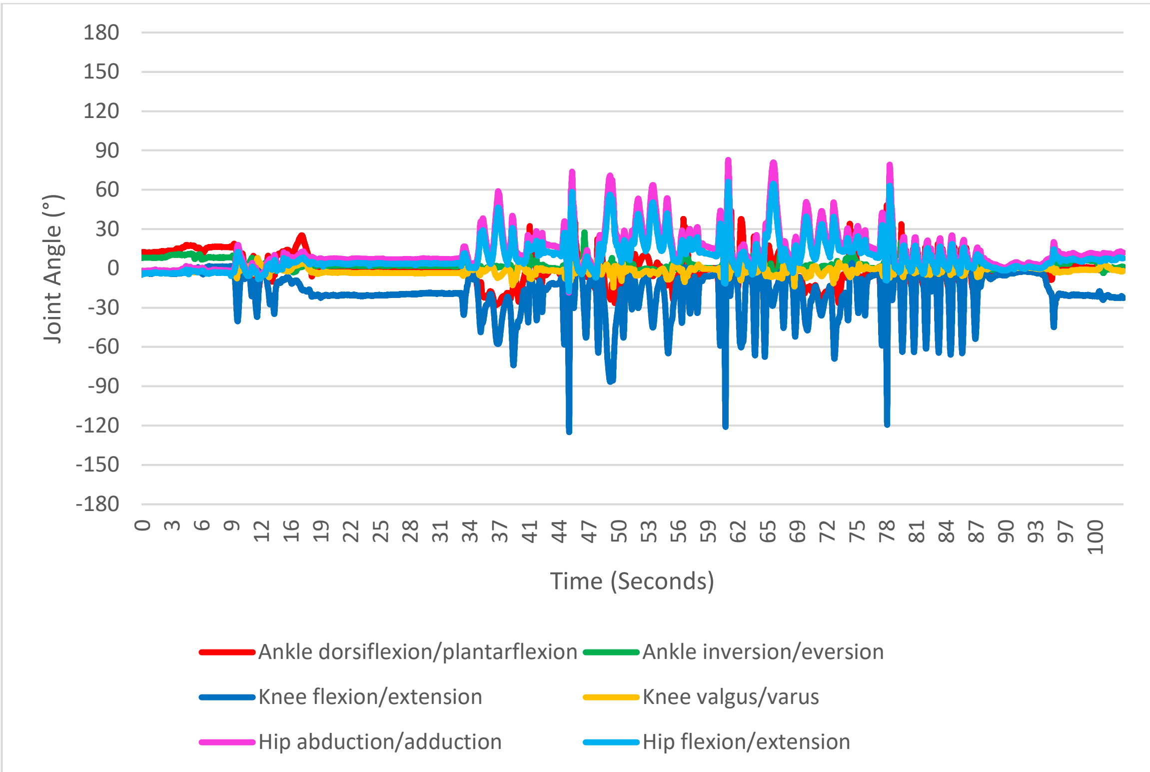


Figure 33E. Participant 5 – Drop Kick from the Right

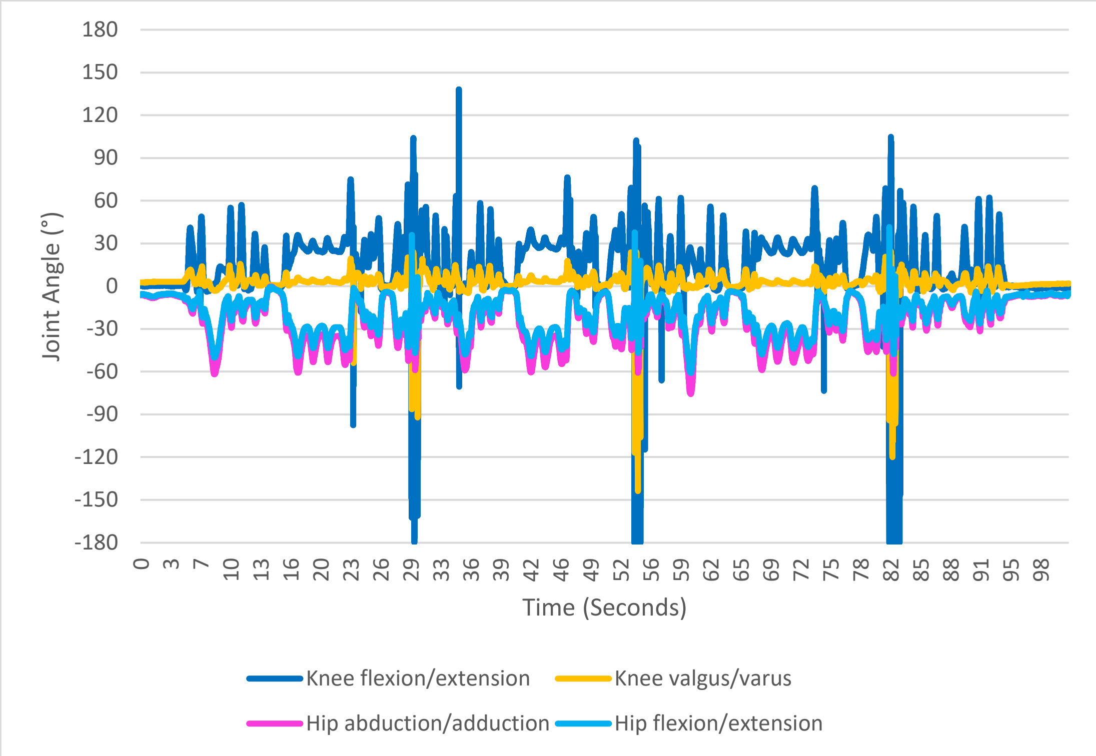


Figure 33F. Participant 6 – Drop Kick from the Centre

Figure 33G. Participant 7 – Drop Kick from the Left

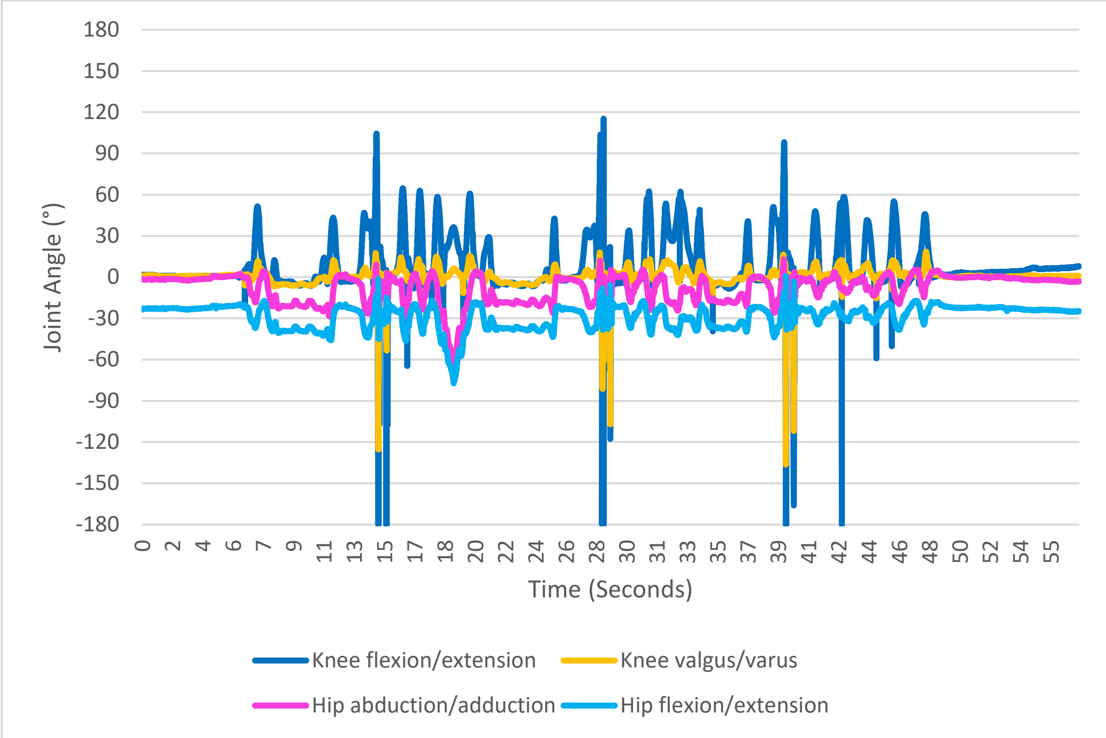


Figure 33H. Participant 8 – Drop Kick from the Centre

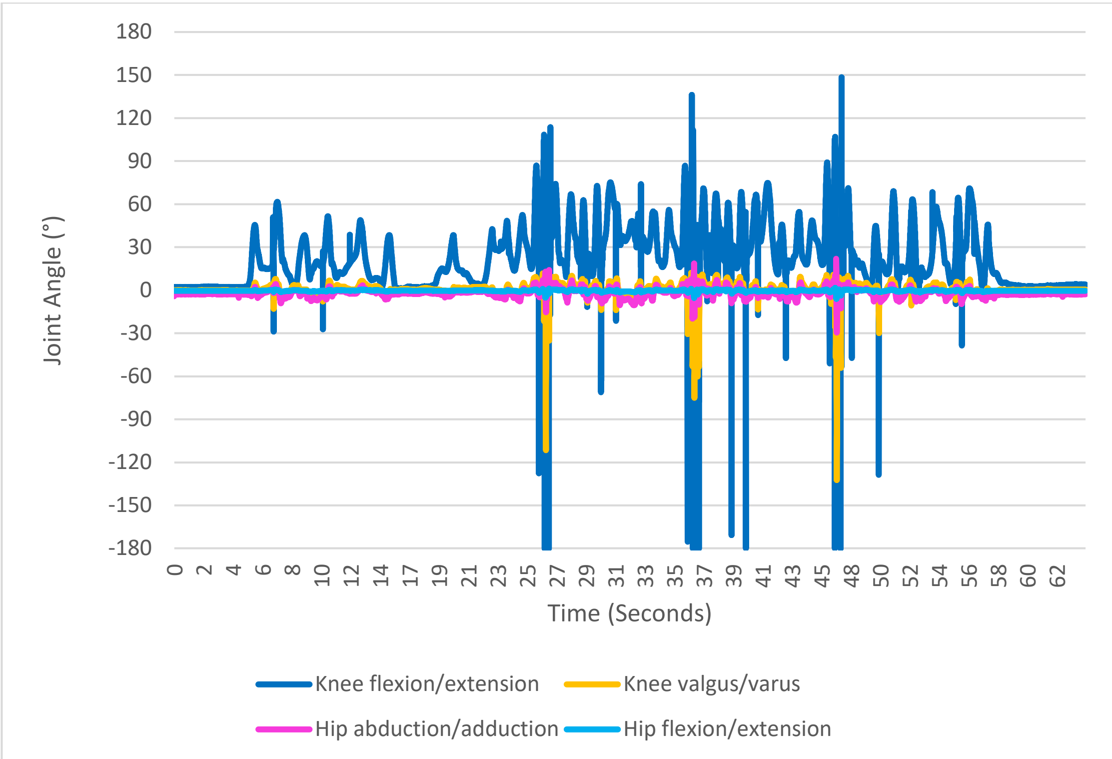


Figure 33I. Participant 9 – Drop Kick from the Centre

Figure 34. Place Kick Electrogoniometer Data, presented graphically in Microsoft Excel

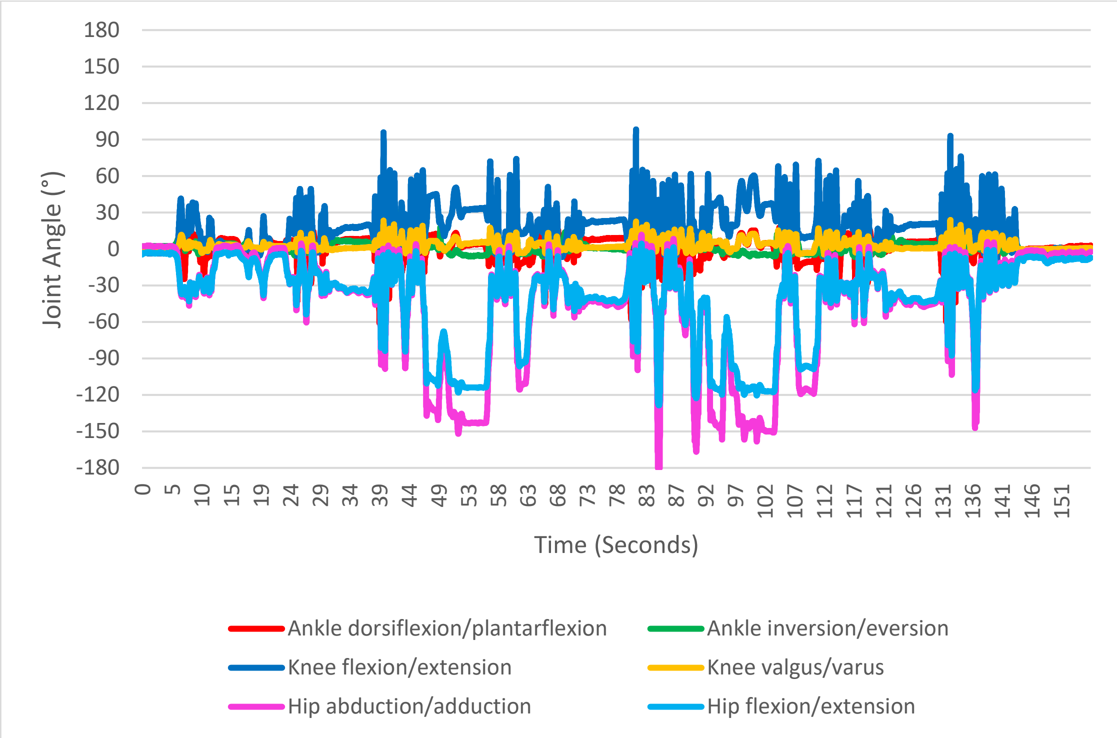


Figure 34A. Participant 4 – Place Kick from the Centre

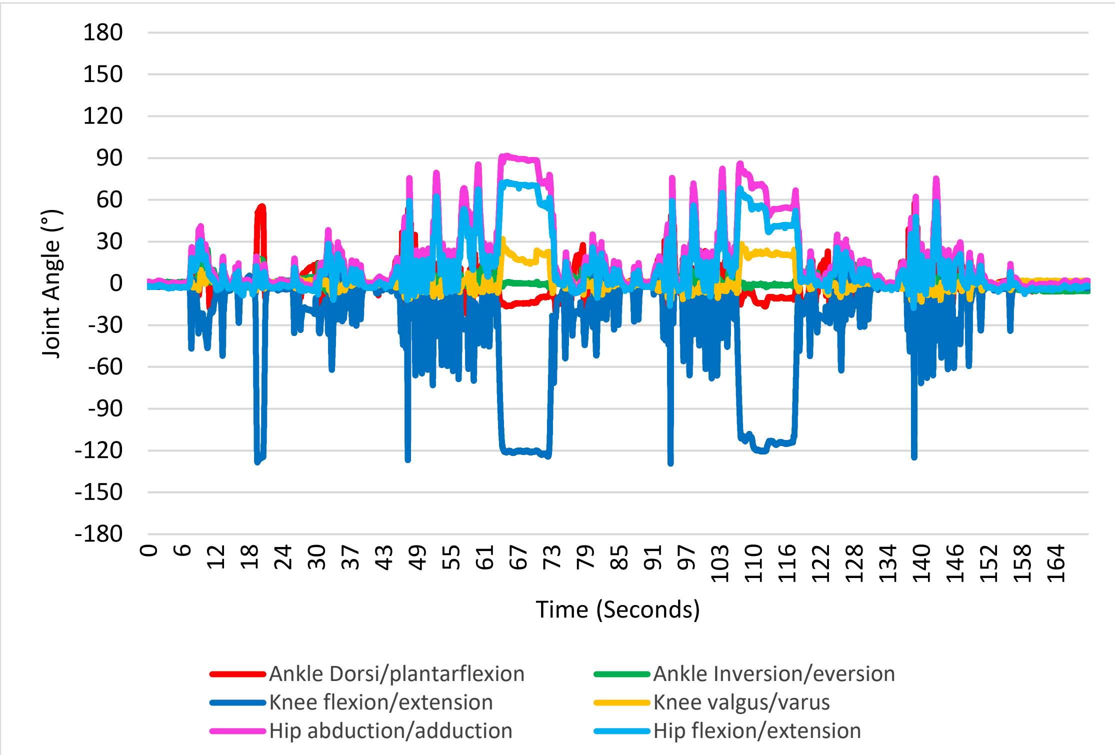


Figure 34B. Participant 5 – Place Kick from the Centre

Figure 34C. Participant 6 – Place Kick from the Centre

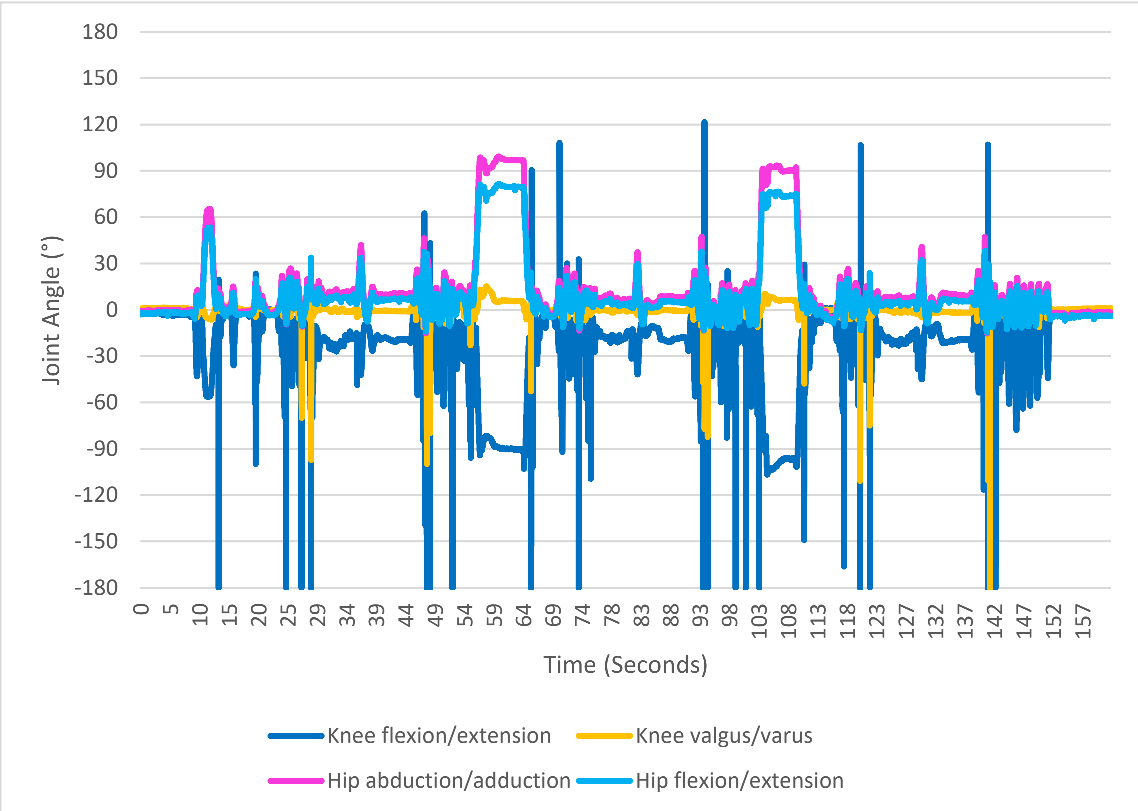


Figure 34D. Participant 7 – Place Kick from the Centre

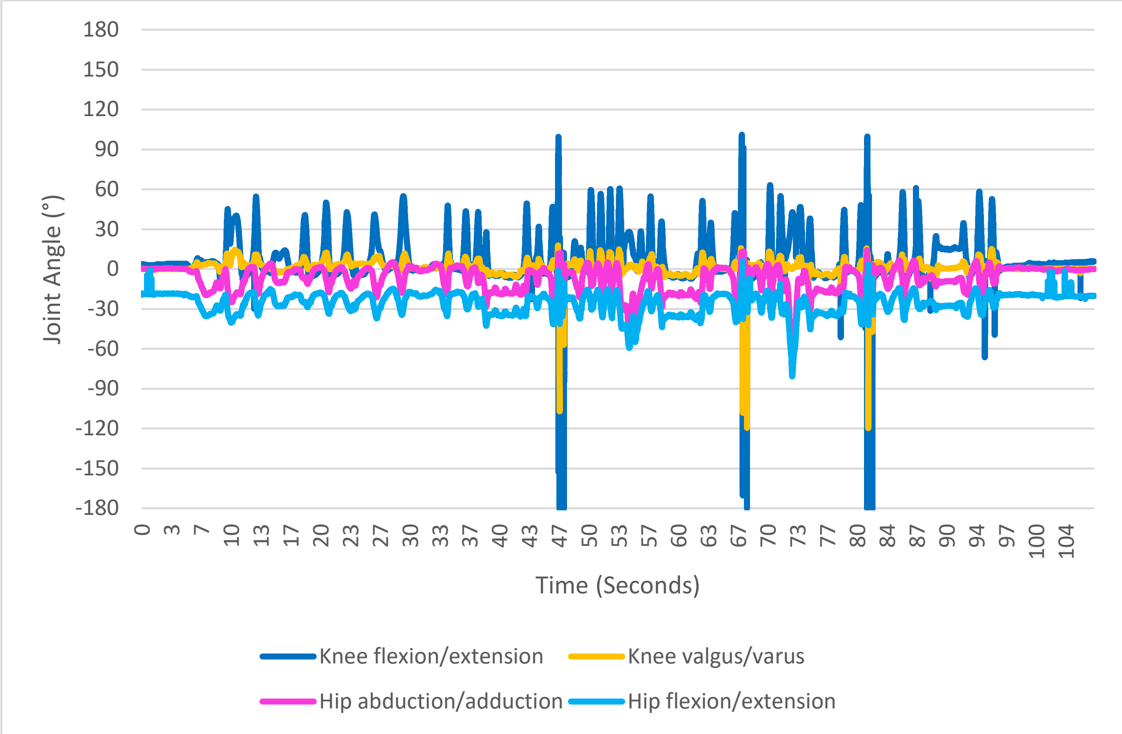


Figure 34E. Participant 8 – Place Kick from the Centre

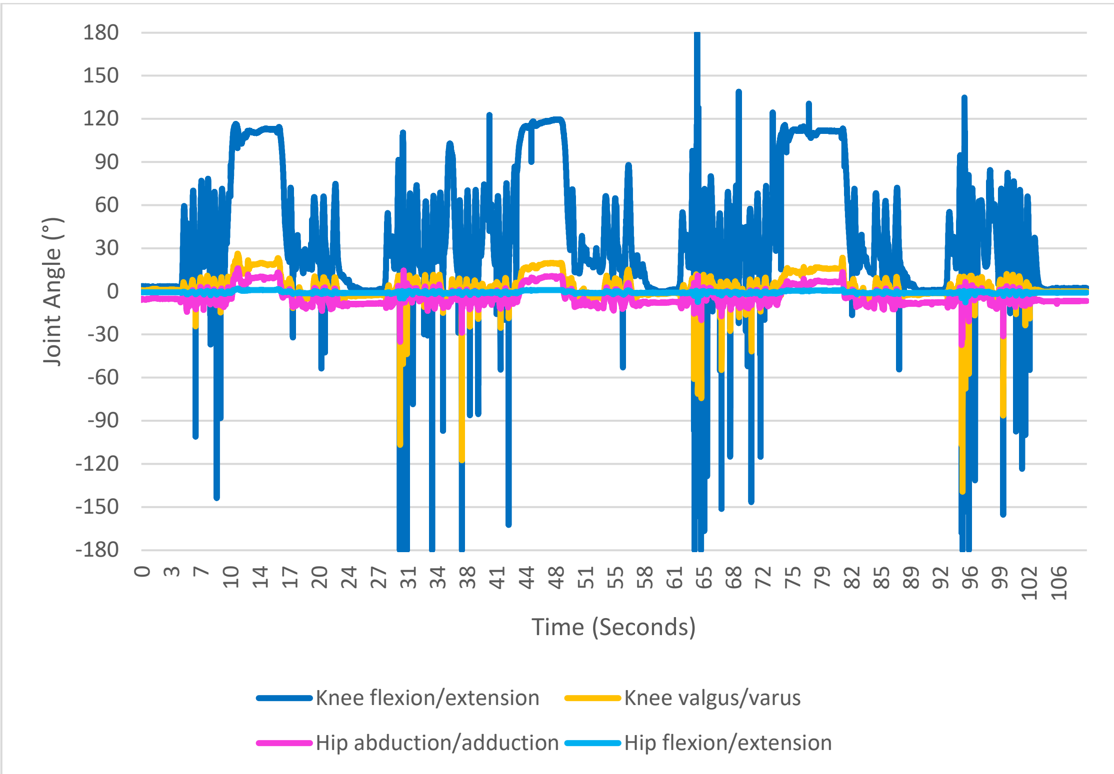


Figure 34F. Participant 9 – Place Kick from the Right

5.2.2.2 Range of Motion

The plotted electrogoniometer data was analysed to extract maximum and minimum ranges of motion for each joint during participants' kicking trials. Joint angle data was collected for each trial for each participant. Mean peak angles for the ankle, hip, and knee are found in Table 13 (drop kicks) and Table 14 (place kicks). This data has been filtered at a frequency of 20Hz, as outlined in 4.4.2.2. A full results table of filtered and unfiltered data can be found in Appendix 28.

5.2.2.3 Qualitative Review

A qualitative review of the electrogoniometer data by the research team highlighted a significant degree of background noise in some of the kick trial recordings. Many joint angle plots, especially those at the ankle and hip, span well beyond the expected range of motion, with some plotted graphs depicting a curve of -180-180°. In such instances, these results were determined to be inappropriate for inclusion and listed as "not applicable (N/A)". Filtering was applied to this data, with results still considerably outside the anticipated range of motion.

The issue of data distortion was particularly evident in drop kick recordings for Participants 1 (Figure 33A) and 5-9 (Figure 33E-I), and in place kick recordings for Participants 6-9 (Figure 34C-F). The data collected for Participants 2-5 was more consistent with normative values for kicking range of motion; however, the researchers remained cautious in their trust of these results. Further analysis was deemed necessary by the research team to confirm the inaccuracy of the results for Participants 1 and 5-9, and to validate the legitimacy of the seemingly more consistent data recorded for Participants 2-4.

During this review, it was also noted that hip abduction/adduction and flexion/extension ranges of motion were very similar for all participants. This may have a been as result of cross talk between the wires and recording due to the position of the sensor under participants' shorts, which may have distorted the recordings. Also of interest was the fact the abduction/adduction values seemed to more accurately reflect the ranges expected in the sagittal plane. This may have arisen as a consequence of the use of the SG150B electrogoniometer at the hip, as recommended by Biometrics Ltd. Traditionally a spinal sensor, this electrogoniometer would normally be attached to a participant's back, with the flexion/extension of the spine moving the device in the same plane as hip abduction/adduction. The research team made the executive decision to relabel these results for this reason. It was also observed that the data collected for left footed kickers was presented differently than other kickers, with maximum values listed as minimum values and negative results reported as positives, and vice versa. The researchers hypothesised that this was because the electrogoniometers are one sided and were positioned in the opposite direction on left-dominant kickers compared to the right; this resulted in angles for flexion being presented as extension for example. These values were renamed, and the appropriate direction of movement applied. Finally, the researchers noted that results for hip joint angles across most participants were listed in the opposite direction to a normal movement pattern. For example, values expected for maximum flexion were presented as maximum extension and vice versa. For the purpose of further analysis, the research team deemed it necessary to swap the direction and labels of these results to their normative values. The results presented in Table 13 and 14 are the corrected versions of the original results.

Table 13. Biometric Goniometer Joint Angles for Drop Kicks

Player	Kicking Foot	Ankle (°)				Knee (°)				Hip (°)			
		Dorsi/Plantar Flexion		Inversion/Eversion		Flexion/Extension		Valgus/Varus		Flexion/Extension		Abduction/Adduction	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
P1	Right	10.06	-69.30	N/A	N/A	N/A	N/A	N/A	N/A	94.36	-2.82	35.08	-5.67
P2	Right	6.15	-43.18	26.61	-3.32	88.57	-11.08	25.89	-9.57	11.91	-18.17	2.69	-1.57
P3	Right	9.85	-56.39	24.00	-4.42	90.27	-15.57	18.55	-10.99	90.02	-9.94	5.61	-74.57
P4	Right	12.07	-45.52	19.49	-8.49	91.77	-8.15	21.11	-3.47	86.97	-8.54	-7.31	-79.93
P5	Left	11.76	-40.59	19.57	-10.02	116.66	-11.33	13.28	-7.45	81.47	-9.53	9.55	-64.78
P6	Right	163.39	-166.80	124.52	-122.78	96.76	-101.31	23.25	-88.56	59.58	-1.52	27.47	-44.44
P7	Left	158.77	-157.22	168.20	-141.25	94.24	-1.71	2.14	-75.76	56.05	-9.60	11.30	-43.11
P8	Right	176.73	-154.82	147.64	-162.04	94.20	-83.60	15.61	-85.93	23.83	-8.92	-10.49	-40.36
P9	Right	167.33	-165.48	170.19	-165.81	96.38	-88.05	10.06	-69.56	27.71	-9.09	0.82	-4.57

Table 14. Biometric Goniometer Joint Angles for Place Kicks

Player	Kicking Foot	Ankle (°)				Knee (°)				Hip (°)			
		Dorsi/Plantar Flexion		Inversion/Eversion		Flexion/Extension		Valgus/Varus		Flexion/Extension		Abduction/Adduction	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
P4	Right	16.74	-56.85	19.75	-7.28	95.40	-11.68	22.62	-5.63	104.49	-2.16	2.50	-86.83
P5	Left	26.07	39.72	9.09	-10.23	122.71	-8.72	10.14	-10.93	70.83	-12.53	14.65	-53.84
P6	Right	174.06	-165.88	147.41	-146.77	96.51	-120.04	22.90	-93.72	65.41	-2.64	8.71	-51.77
P7	Left	161.82	-169.75	162.36	-145.80	-0.65	-91.49	3.52	-64.41	46.24	-13.91	12.32	-37.56
P8	Right	175.68	-173.58	163.30	-139.51	92.64	-103.00	15.27	-66.27	36.47	-6.24	11.55	-54.65
P9	Right	173.68	-148.63	159.92	-161.96	92.23	-67.49	9.78	-68.37	29.45	-7.41	0.49	-4.76

5.2.3 Further Analysis

5.2.3.1 Manual 2D Analysis

Researchers carried out an approximate 2D analysis of the joint angles of maximum hip extension, knee flexion, and hip flexion using a line and protractor method on still frames cut from kicking video recordings. The resulting angles are listed in Table 15.

Table 15. Manual 2D Analysis of Joint Angles

Player	Kicking Foot	Drop Kicks (°)			Place Kicks (°)		
		Max Hip Extension	Max Knee Flexion	Max Hip Flexion	Max Hip Extension	Max Knee Flexion	Max Hip Flexion
P1	Right	-32	124	90			
P2	Right	-21	100	98			
P3	Right	-18	109	123			
P4	Right	-16	121	103	-22	90	115
P5	Left	-33	121	136	-33	115	130
P6	Right	-19	108	127	-33	103	121
P7	Left	-28	101	116	-28	101	107
P8	Right	-16	117	104	-32	100	105
P9	Right	-18	94	84	-33	142	90
Median		-19	109	104	-32.5	102	111

5.2.3.2 Pose Estimation

A third method of joint range of motion analysis was implemented to validate the electrogoniometer results. OpenPose pose estimation software was applied to place kicks only. Maximum hip and knee angles are found in Table 16.

Table 16. OpenPose Analysis of Place Kicks

Player	Kicking Foot	Place Kick (°)		
		Max Hip Extension	Max Knee Flexion	Max Hip Flexion
P4	Right	-29.3	85.7	26.8
P5	Left	-43.9	116.6	125.2
P6	Right	-19.2	110.2	107.4
P7	Left	-34.5	89.5	64.2
P8	Right	-22.8	105.1	109.1
P9	Right	-36.5	102.5	66.4
Median		-28.7	103.8	86.9

5.2.4 Comparison of Analysis Methods

5.2.4.1 Comparison of All Kicking Data

The research team identified significant distortion in the electrogoniometer data for a number of participants in their qualitative review of graphs and figures. To assess the effect of this background noise, statistical tests were performed to compare the data collected by wearable sensors to the other analysis methods described above for the angles of maximum hip extension, knee flexion, and hip flexion.

5.2.4.1.1 Place Kicks

One-way ANOVA tests were carried out on place kick data from the electrogoniometers, 2D manual analysis, and pose estimation programme. The results in Table 17 indicate that there were significant differences between the three methods in the analysis of place kicks in all participants for maximal hip flexion and extension. There was no significant difference between the methods for maximal knee flexion. This indicates that a mean value of 103.1 ± 5.1° for maximal knee flexion during place kicks by female rugby players may be reasonable.

Table 17. Comparison of Place Kick Results for Electrogoniometers, 2D Analysis, and OpenPose

Player	Kicking Foot	Max Hip Extension (°)			Max Knee Flexion (°)			Max Hip Flexion (°)		
		EG	2D	OP	EG	2D	OP	EG	2D	OP
P4	Right	-2.16	-22	N/A	91.77	90	85.7	86.97	115	N/A
P5	Left	-12.53	-33	-43.9	116.66	115	116.6	81.47	130	125.2
P6	Right	-2.64	-33	-19.2	96.76	103	110.2	59.58	121	107.4
P7	Left	-13.91	-28	-34.5	94.24	101	89.5	56.05	107	64.2
P8	Right	-6.24	-32	-22.8	94.20	100	105.1	23.83	105	109.1
P9	Right	-7.41	-33	-36.5	96.38	142	107.9	27.71	90	66.4
Mean		-7.482	-30.17	-31.38	98.34	108.5	102.5	55.94	111.3	94.46
P Value		<0.0001*			0.4549			0.030*		

5.2.4.1.2 Drop Kicks

An unpaired T-test was performed on data from the electrogoniometer recordings and the 2D manual analysis for drops kicks from all participants (Table 18). This also highlighted significant differences between the two methods, when the data identified by the research team as distorted was included.

Table 18. Comparison of Drop Kick Results for Electrogoniometers and 2D Analysis Methods

Player	Kicking Foot	Max Hip Extension (°)		Max Knee Flexion (°)		Max Hip Flexion (°)	
		EG	2D	EG	2D	EG	2D
P1	Right	-2.82	-32	N/A	124	94.36	90
P2	Right	-18.17	-21	88.57	100	11.91	98
P3	Right	-9.94	-18	90.27	109	90.02	123
P4	Right	-8.54	-16	91.77	121	86.97	103
P5	Left	-9.53	-33	116.66	121	81.47	136
P6	Right	-1.52	-19	96.76	108	59.58	127
P7	Left	-9.60	-28	94.24	101	56.05	116
P8	Right	-8.92	-16	94.20	117	23.83	104
P9	Right	-9.09	-18	96.38	94	27.71	84
Mean		-8.681	-22.33	96.11	110.6	59.10	109
P Value		0.0001*		0.0088*		0.0008*	
CI		-19.51 to -7.798		4.211 to 24.69		24.41 to 75.39	
Mean difference ± SEM		-13.65 ± 2.762		14.45 ± 4.804		49.90 ± 12.02	

5.2.4.2 Comparison of Meaningful Data

As per the qualitative review, electrogoniometer place kicking data for a number of participants was subject to significant distortion. Place kicking results for Participants 4 and 5 and drop-kicking results for Participants 2-5 were least impacted by background noise and showed most consistency with the values expected. As such, this data was extracted for further analysis to establish maximal kicking ranges.

5.2.4.2.1 Place Kicks

One-way ANOVAs of place kick joint angles found no significant difference between the analysis methods (Table 19). These results indicate that a mean maximal hip extension angle of -26.25 ± 18.31, knee flexion angle of 102.73 ± 1.66°, and hip flexion angle of 110 ± 22.92° are used by female rugby players when performing place kicks.

Table 19. Comparison of Meaningful Drop Kick Results for Electrogoniometers, 2D Analysis, and OpenPose

Player	Kicking Foot	Max Hip Extension (°)		Max Knee Flexion (°)		Max Hip Flexion (°)	
		EG	2D	EG	2D	EG	2D
P1	Right	-2.82	-32	N/A	124	94.36	90
P2	Right	-18.17	-21	88.57	100	11.91	98
P3	Right	-9.94	-18	90.27	109	90.02	123
P4	Right	-8.54	-16	91.77	121	86.97	103
P5	Left	-9.53	-33	116.66	121	81.47	136
Mean		-9.8	-24	96.82	115	72.95	110
P Value		0.0112*		0.052		0.068	
CI		-24.18 to -4.222		-0.2391 to 36.60		-3.491 to 77.60	
Mean difference		-14.20 ± 4.327		18.18 ± 7.790		37.05 ± 17.58	

5.2.4.2.2 Drop Kicks

Unpaired T-tests of joint angles during drop kicks indicated that there remained a significant difference between the electrogoniometer and 2D analysis method for maximal hip extension values (Table 20). Differences between the maximal knee and hip flexion angles were not significant. It is therefore reasonable to assume that female rugby players perform drop kicks with a mean maximum knee flexion angle of 105.91 ± 12.86° and a maximal hip flexion angle of 91.48 ± 26.2°.

Table 20. Comparison of Meaningful Place Kick Results for Electrogoniometers and 2D Analysis

Player	Kicking Foot	Max Hip Extension (°)			Max Knee Flexion (°)			Max Hip Flexion (°)		
		EG	2D	OP	EG	2D	OP	EG	2D	OP
P4	Right	-2.16	-22	N/A	91.77	90	85.7	86.97	115	N/A
P5	Left	-12.53	-33	-43.9	116.66	115	116.6	81.47	130	125.2
Mean		-7.345	-27.5	-43.9	104.5	102.5	101.2	84.22	122.5	125.2
P Value		0.1			0.99			0.065		

5.2.4.3 Recording Issues and Adaptations

As stated in 4.4.1 of Methods, upon review of the recordings taken with the electrogoniometer devices, it was found that a high degree of background noise was present in many of the trials. The Biometrics data collected during each kick was scrutinised by engineers, RN and CS, with many kick graphs appearing to span beyond the expected range of motion for each joint. Each plot was then reviewed by physiotherapists, MB and FW, who confirmed that many of the ranges reported were not physically possible to achieve, either during kicks or in passive movement. These included kicks with reported joint angles ranging from -180-180°. A Butterworth 20Hz filtered was applied across the board in an effort to reduce some of the distortion on the plots. This was moderately successful in smoothening erratic curves for some trials; however, for those that jumped from end range to end range, the filtering process only succeeded in masking the turbulence of the graphs, while also failing to bring the plots back to an expected range of motion. Kickers and trials were subjectively reviewed by the research team and those that were subjectively deemed reasonably legitimate were examined further.

Given the discrepancies in the electrogoniometer data, the research team explored other methods of evaluating kinematic data from the kick trials and validating the results from the Biometrics devices. As discussed in 4.4.2.3 of the Methods, analysis of the video footage and resulting still images were used for this purpose. Use of the camera during the kicking sessions was not thought to be feasible until the morning of testing. The original video recording protocol involved the use of three GoPro cameras controlled by three engineering colleagues for the duration of the trials. Due to impractical logistics, restricted access to the HPC, and unavailability of said cameras, the on-site researchers did not anticipate that collecting video data would be possible. As a result, the camera was roughly set up between 30-45° angle to the kicking tee for some trials and at perpendicular angles to the tee in other shots. This was to allow for a number of different perspectives on the kicks; however, the precision of these angles was limited, particularly after Participant 2, when I was the only researcher on site to set up and carry out the testing procedure.

Two-dimensional (2D) analysis was performed on the video footage by engineering colleagues using Pose Estimation software and by MB and RN using the manual protractor method. The approximate recording angles of the video footage may have limited the accuracy of these analyses. For the OpenPose programme, some of the angular overlays did not follow the joint centres consistently throughout the kick trials. For the protractor method, joint angles were mapped onto still frames from the video footage. The validity of this process may have been affected by the varying angles at which the images were taken; however, this was combined with the anatomical and biomechanical knowledge of the research team and compared to the other analysis methods to verify the legitimacy of the results.

CHAPTER 6:

DISCUSSION

6.1 Aims of the Research Project

Women's rugby is a widely under-researched sport, despite its rapid international growth in recent years. Many aspects of the game have yet to be explored from a female-specific standpoint, including the skill of kicking. The goal of this research project was to address the gap in the literature regarding kicking in women's rugby. To do so, the research team originally aimed to investigate the kicking kinematics of female rugby players, compare them to their male counterparts, and identify any technical or biomechanical differences in performance that may be determined by sex. As a first step, we carried out a systematic review to compare the kinematics and kinetics of kicking in male and female athletes in field-based sports. The goal of this review was to gain insight into research already carried out in this area, and to inform the methods used, variables explored, and outcomes expected in the researchers' own investigation. These findings were discussed in Chapter 2 for clarity and ease of reading; however, I will refer to a number of these results in the following sections.

The original aims and objectives of this study were amended several times over the course of the project due to unforeseen circumstances. The global pandemic had significant implications for all aspects of this study, including the recruitment strategy, sample size, testing location, assessment battery, and project duration. Considerable pragmatism was required to adapt to the ever-evolving health guidelines and government restrictions over the past two years. In conjunction with my colleagues, I developed various iterations of the study protocol in an effort to ensure testing could take place in as robust a manner as possible when it was safe to do so. However, I remained hopeful throughout the process that it would be possible to complete the research as originally planned at some point during the project. Unfortunately, due to the gravity of the Covid-19 crisis in Ireland and the extent of the restrictions in place for many months, this was not feasible. As such, the objectives of this project were adapted once again. I aimed to develop a study protocol to explore the kicking kinematics of elite female rugby players and to evaluate the associated processes and outcomes in a pilot study. The resultant protocol was not as robust as the original iterations, with limitations affecting a number of aspects. However, considerable learnings were gained through the undertaking of this project; particularly with regards to the methodology and equipment used. With this information, my colleagues and I are keen to carry out more robust and powerful studies in this area in the future. I am in the process of applying for funding to facilitate further investigation into the biomechanics of kicking in women's rugby.

6.2 Results of the Research Study

As described previously, the results of this pilot test were not as robust as originally hoped, due to technical difficulties with the electrogoniometers. The data from these devices was subject to significant distortion; as a result, the analyses that could be performed on individual participants' kicking trials were limited. However, through filtering and statistical processing, some meaningful data could be extracted and compared to the demographic and accuracy results collected.

6.2.1 Meaningful Results

6.2.1.1 Range of motion

Meaningful angles of joint range of motion for the hip and knee were calculated for place and drop kicks by filtering and extracting data from athletes whose trials were least impacted by background noise. For place kicks, these were Participant 4 and 5, and for drop kicks, they were Participants 1-5.

The mean maximum hip extension angle during place kicks for female participants in this study was -26.25 ± 18.31°. There is limited research investigating this variable in rugby place kicks, however, given the mechanism and technique used to carry out this kicking style, it can be broadly compared to a soccer instep kick (Sinclair, Taylor, et al., 2014). However, there is considerable variation in values for maximal hip extension during kicks in soccer. R. H. Brophy et al. (2010)

reported a value of -9.3 ± 6.8° for male kickers during an instep soccer kick, while Navandar et al. (2016) recorded angles of -12.42 ± 7.76° and -14.73 ± 9.37° for men and women, respectively. Levanon and Dapena (1998) reported maximum hip extension to be −29 ± 13° and Langhout et al. (2017) recorded -31.8 ± 6.0° for maximal effort instep kicks performed by men. Female soccer players had maximum hip extension angles of -32.1 ± 1.7° compared to -24.7 ± 6.8° in males in a study by Smith and Gilleard (2016). These greater values of hip extension are more comparable to the results of this study than the more acute angles. The maximum hip flexion value of 110.73 ± 22.92° appears to be an infrequently investigated variable in instep and place kicks alike. Lombard (2018) reported hip flexion angle of between 16 and 36.6° during rugby place kicks, which is vastly different to our results. The exact reason for this disparity is unknown; it may be that Lombard (2018) only included peak ranges of motion that occurred up to the point of ball contact, but this is not definitively stated.

A mean maximum knee flexion angle of 102.73 ± 1.66° was found for place kicks in this study. This is within the range of values found by Lombard (2018) during rugby kicks (89.6° to 126.9°) and comparable to the peak knee flexion angle of 103.23 ± 7.47° reported by Sinclair, Taylor, et al. (2014). The knee electrogoniometer was the most consistent device during testing, with minimal distortion and subjectively acceptable results observed in all participants. The similarity between the findings of this study and that of Sinclair, Taylor, et al. (2014) provides further validation for the results from this sensor. However, the knee flexion angles recorded in this study were slightly less than the range of peak angles used male place kickers in research by Hébert-Losier et al. (2020) (107.7 ± 4.1° to 120.4 ± 0.9°). This study used a whole-body 3D marker-based motion capture system, which may account for the differences between it and our study.

The systematic review highlighted the importance of ankle and trunk range of motion in differentiating male and female kickers in soccer. Men strike the ball with their ankles in significantly greater angles of plantarflexion than women. There is limited research on ankle kinematics during place kicks in rugby; the research team hoped to explore this variable in female players using electrogoniometers in this study. However, of all devices, the ankle sensors were most impacted by distortion. No meaningful data could be extracted for this joint. Future research investigating ankle angles at ball strike during place kicks would be of interest to coaches and players alike. Increased ankle plantarflexion is associated with greater ball velocities in soccer (Asami & Nolte, 1983). This concept may also apply to rugby, with elite coaches advising athletes to kick the ball with their "toe down, laces up; promote the hard part of the foot striking through the ball" to achieve optimum impact mechanics (Bezodis & Winter, 2014); however, no quantitative research has been carried out to confirm this. Future studies exploring kicking kinematics in male and female rugby players could include an analysis of ankle mechanics.

Trunk range of motion was also identified as a point of significant difference between male and female kickers in soccer in our systematic review. Females use greater trunk flexion than males, particularly during the follow through, to slow their forward momentum post-kick (Shan, 2009). This method is not seen in men, who use a jump to dissipate momentum. A "release mechanism… at the end" is also evident in rugby place kicking (Bezodis & Winter, 2014). This is described as "a hop or a skip, it may be a run, a step on your kicking foot afterwards". While researchers were interested in exploring whole body mechanics during kicks as part of this study, the challenges presented by the testing equipment limited this opportunity. Had the Simi Motion Capture system been operational in the field, the research team may have been able to gain insight into trunk movement, as well as kicking leg motion. However, the decision to proceed with electrogoniometers as the testing devices removed this possibility. Only three sensors were available to researchers due to funding constraints and recording the kinematics of the kicking leg was prioritised in this instance.

Investigation of whole body biomechanics during kicks by female rugby players would also be of interest in terms of exploring the use of tension arcs in this athlete cohort. This technique was first described by Shan and Westerhoff (2005) and is achieved through kicking-side hip extension, knee flexion, and trunk rotation to the non-kicking side, and compounded by horizontal extension and abduction of the non-kicking side shoulder. This “winds up” the body, creating a stretch across the torso and abdominals and increasing potential energy (Langhout et al., 2017). A greater range of motion across these joints enhances the stretch applied to the involved musculature, allowing them to contract with more force as a result of the stretch-shortening cycle (Bober, Putnam, & Woodworth, 1987; Komi, 1984). The tension arc is released in a quasi-whip like motion of the kicking leg towards the ball, longitudinal rotation of the trunk, and horizontal flexion and abduction of the non-kicking side shoulder (Shan & Westerhoff, 2005). This movement produces greater foot velocity at ball contact, increasing the resultant ball velocity (Dörge et al., 2002).

Tension arcs are a feature of kicking in rugby and are thought to play a fundamental role in the success of place kicks (Bezodis & Winter, 2014). However, there may be a trade-off between kicking speed and accuracy when using this mechanism. Atack et al. (2019) found that inaccurate place kickers had greater thorax rotation on release of their tension arc than their accurate counterparts, which resulted in their shots missing the target. A minimal amount of thoracic angular momentum at ball impact is associated with more successful rugby place kicks (Bezodis et al., 2007). As such, use of a tension arc may have a negative impact on the performance of this skill in rugby (Atack et al., 2017, 2019). Notably, research investigating tension arcs in rugby kicking has only been carried out with male athletes. Thus, future research investigating the biomechanics of kicking in women’s rugby could explore this technique to establish its effect on kicking velocity and accuracy. The production of tension arcs is an effect of training, as it is only observed in skilled players (Shan, 2009). Anecdotally, it is noted that many female players begin playing rugby later in life than their male counterparts (Waterman, 2019). They thus have a younger playing age, with less coaching experience. Exploring the presence or absence of tension arcs in female kickers would provide interesting insight into their exposure to kicking-specific coaching and training.

6.2.1.1.1 Accuracy

Analysis of kicking accuracy in this study found a 67% success rate of shots on target. Kicking accuracy is inherently important in rugby (Atack et al., 2019), as up to 45% of points scored in men's matches come from place kicks. In a review of 582 international rugby matches (2002-2011) by Quarrie and Hopkins (2015), it was found that if kicking success percentages for two opposing teams were reversed, the outcome of the game would have changed in favour of the losing team in 14% of cases. A total of 2196 points were scored in the Men's Rugby World Cup 2019 in Japan; of these, 1425 were scored in 285 tries, with the remaining 771 coming from penalties and conversions. Kicks on goal accounted for 35% of scores in this competition. Of 1549 points scored in the Women's Rugby World Cup (WRWC) 2017 in Ireland, 1235 points resulted from 247 tries and 317 points from kicks (254 from conversions and 60 from penalties). Shots on goal only represented 20% of points scored in the women's competition, with a 51% success rate in conversions. The accuracy percentage for our study (67%) was higher than this. However, our testing environment was controlled, with no spectators or external pressures, which may account for the differences in outcomes. There is a perception across sporting culture and the media that women play a more free-flowing running brand of rugby with less kicking in play and at goal (Rowan, 2019), due to poor technical and tactical ability to perform this skill (Waterman, 2019). The above data indicate that there is a disparity between men's and women's rugby in terms of kicking performance and outcomes, however further investigation in this area is needed to properly quantify these differences.

Exploring the mechanisms behind which accurate kicks are achieved by female athletes should also be considered. Understanding how women kick under different constraints of ball velocity and accuracy could be beneficial in improving female-specific coaching cues for this skill. When prioritising accuracy, reduced ranges of motion and joint linear velocities are observed in place kicks by men (Sinclair et al., 2017). This is accompanied by altered swing foot planes and last step lengths in an effort to produce successful kicks (Bezodis, Atack, Willmott, Callard, & Trewartha, 2018; Cockcroft & Van Den Heever, 2016). These differences in technique should be noted by researchers seeking to carry out kicking analyses with female kickers to account for how kicking patterns may change depending on the instructions provided to athletes.

6.2.1.2 Demographic Information

Demographic information was collected as part of this study for the purpose of contextualising performance and outcomes. The researchers had hoped to perform a series of analyses comparing this background information to the performance outcomes recorded during the kicking assessments. Due to the distortion of the electrogoniometer results, meaningful individual associations could not be made. However, the data gathered offers some interesting insight into the experience of female rugby players performing at the highest level in Ireland.

6.2.1.2.1 Rugby Playing Experience

Information on the participants' rugby playing experience was collected with the aim of providing a basis from which to interpret their kicking performances. While it was not possible to make associations between years playing and kinematic outcomes for individual players, the playing histories of the participating athletes tells an interesting story about the state of women's rugby in Ireland. For many years, it has been anecdotally reported that most female rugby players begin playing later in life (Waterman, 2019). Unlike their male counterparts who are introduced to the game at a young age, women are more likely to pick up rugby when they are older than 16 years old (Joncheray & Tlili, 2013). The participants in this study appear to be change from the norm, with the majority of athletes (5/8) starting their rugby careers at age grade level. In recent years, the IRFU have placed significant emphasis on the expansion of the women's game. In 2015, the IRFU Women's Rugby Long Term Player Development model was launched, outlining a blueprint for the development of female players of all ages and abilities. The increasing profile of the national women's team and successful hosting of the Women's Rugby World Cup in 2017 have seen a significant increase in participation in the sport across Ireland (Lunn & Kelly, 2019). The IRFU Women in Rugby Action Plan 2018-2023 aims to build on this momentum to grow the game across all levels: adult, youth, schools, and third level (Irish Rugby Football Union, 2017). The development pathway of athletes participating in this study indicates the success of these programmes, with players progressing from underage and university level rugby teams to an elite performance environment.

Many women who join rugby later in life have been involved with other sports from a young age (Joncheray & Tlili, 2013). This is reflected in the sporting backgrounds of participants in this study. Of the nine included athletes, eight played other sports before or while they started their rugby career. Gaelic Football and soccer were the most commonly reported previously played sports; both of which are field-based kicking sports. The basic kicking skills gained through participation in these sports may have transferred to rugby, which enabled these athletes to achieve a high level of kicking performance. For those who join rugby in adolescence or adulthood, there is a huge breadth of skills to be gained within a short time frame. The fundamental actions of passing, tackling, and falling are priorities to be learned before taking to the field (Waterman, 2019). As a result, kicking is often an afterthought in terms of initial skill development. Coaches tend look to players with previous kicking experience from other sports and build upon those, rather than fostering this skill across the board (Waterman, 2019). It is therefore little surprise that the majority of participants in this study have a background in kicking sports.

It is also interesting to note the level of kicking-specific coaching received by participants in this study. Many hours of training and practice are undertaken by elite kickers in an attempt to improve their kicking technique and success rate (Bezodis et al., 2007). For high performing male athletes, these hours are often spent with specialised kicking coaches who work with elite teams (Chris Pocock, Bezodis, Davids, Wadey, & North, 2020). For female kickers, this is not the case. It is anecdotally acknowledged that most women's team do not have a dedicated kicking coach, even at international level. This is reflected in the coaching histories of players in this study. While the majority of participants have received some form of kicking coaching during their careers, all described the process as infrequent or short-term. When learning a skill, the process of motor learning requires direct experience or observation of others to bring about a change in behaviour (Adams, 1971). Repetition and training are necessary to progress an athlete from the early stages of skill development to a phase of automation; where motor sequences become second nature, even in high pressured environments (Fitts, 1964). Consistent practice is required for rugby kickers to improve performance and, without ongoing support and guidance, many of the players in this study may not be achieving the best outcomes for their efforts.

6.2.1.2.2 Anthropometrics

The systematic review conducted as part of this project indicated that significant differences exist between males and females in terms of body size. The authors hypothesised that this may have been a contributing factor in the greater ball velocities produced by male kickers. Greater body size is associated with higher ball velocity across a variety of sports (Debanne & Laffaye, 2011; van den Tillaar & Ettema, 2004; Wong et al., 2014), including soccer (Bekris et al., 2015), which may transfer to other kicking sports. Weight and height details were recorded for participants in this study in an effort to examine the influence of anthropometrics on kicking outcomes in rugby. While it was not possible to perform a sex-based comparison as part of this protocol, the researchers were still interested to see if players of the same gender had different kicking kinematics which could be associated with their stature. However, due to the inconsistency of results in this study, it was not possible to accurately evaluate the kicking outcomes of each individual athlete. As a result, kicking outcomes and body size were not comparable in this way. Future studies could explore this concept as simply as we have proposed here, using body height and weight as a performance comparison. A more robust analysis of body composition may also yield interesting results, as players with greater proportions of lean muscle mass and lower levels of fat mass produce higher velocity kicks of greater accuracy than their less lean counterparts (N. H. Hart et al., 2016; Nicolas H. Hart, Nimphius, Spiteri, & Newton, 2014).

6.2.2 Other Outcomes for Investigation

The research team were interested in exploring a number of other biomechanical variables based on the findings of the systematic review and previous studies. However, due to limitations and constraints at the time of testing, it was not possible to evaluate these outcomes. Future more robust research investigating a wider range of kinematic and kinetic outcomes would be valuable in providing more comprehensive insight into the biomechanics of kicking in women's rugby.

6.2.2.1 Hip and Groin Health

As outlined in early iterations of the research protocol, the research team had intended to perform hip and groin health testing with participants as part of our study. This included a subjective player-reported outcome measure, range of motion assessments, and strength testing. Injuries to the hip and groin region are common in multi-directional field based sports, as athletes are exposed to high levels of rapid changes of direction, twisting, acceleration, deceleration, and kicking (Pizzari, Coburn, & Crow, 2008). Groin pain is frequently reported in kicking athletes and accounts for 11-16% of all injuries in elite male soccer players (Chahla et al., 2019; Pfirrmann, Herbst, Ingelfinger, Simon, & Tug, 2016). This type of injury is the most common non-time loss injury in amateur women's soccer (Langhout et al., 2019). The prevalence of hip and groin injuries is high in men's rugby, as the second most common severe lower limb training injury and among the six most commonly cited injuries across the sport (Brooks & Kemp, 2008; Whitehouse, Orr, Fitzgerald, Harries, & McLellan, 2016). Fly halves perform most kicking in rugby and thus have the greatest proportion of kicking related injuries (Lazarczuk et al., 2020). A systematic review of injuries in women's 15s and 7s rugby reported that the lower limb was the most commonly injured site among female players, however, there was no specific mention of hip and groin involvement (King et al., 2019). Risk factors for injury include previous injury, older age, increased body mass, weak hip adductor muscles, decreased hip abduction, and total hip range of motion (Julianne Ryan et al., 2014). Through an assessment of hip and groin health, we hoped to compare range of motion and strength outcomes to the kinematic data collected during the kicking trials. A secondary aim of this examination was to identify potential risk factors for injury in the participating cohort by carrying out this assessment and compare them to kicking performance outcomes. However, due to protocol changes over the course of the project, this was no longer feasible. Future research examining the hip and groin health of female rugby players would be useful, as this has yet to be formally investigated. It could provide normative data for range of motion and strength for this cohort, as well as identify the prevalence of risk factors for injuries to this region in this playing group.

6.2.2.2 Ball Velocity

Ball velocity was the most commonly investigated outcome of kicking in the systematic review in Chapter 2. A main finding of this paper was that male athletes produced significantly greater ball velocities than females during kicks. The majority of included studies used a 3D optoelectronic motion analysis system, such as Vicon (Oxford Metrics Ltd., Oxford, UK) to investigate kicking kinematics. Ball velocity was recorded by attaching retro-reflective spherical markers to the ball to capture its flight. I had hoped to investigate this performance outcome as part of the original testing protocol. Despite the inability to compare males and females in the final testing plan, evaluating the variability in ball speed between female athletes was of interest to the researchers. The use of three GoPro cameras to record the kick as per the original protocol would have provided sufficient camera footage to facilitated further analysis of ball flight. However, as only one camera was available onsite during testing in the HPC, it was not possible to collect this data. Comparison of accuracy outcomes from this study and the concurring ball velocities would have been an interesting analysis between participants in this study, as well as previous research in rugby and soccer. Atack et al. (2017) found that accurate kickers who successfully kicked the ball between the posts achieved greater ball velocities than those whose kicks dropped short before going over the bar. Athletes who performed inaccurate kicks of sufficient distance produced similar ball velocities to their successful counterparts, however they used a different technique. Successful kickers performed their kicks with more knee extension compared to unsuccessful kickers, who were more hip dominant. The use of a tension arc in the latter group produced greater pelvis-thorax rotation and applied greater longitudinal spin to the ball, which caused their shot to veer away from the target. This paper suggests that while use of a tension arc is effective in producing greater ball speeds in soccer (Shan, 2009; Shan & Westerhoff, 2005), it may not be beneficial in rugby place kicking, which requires a high degree of accuracy.

6.2.2.3 Joint Velocity

Differences in joint velocity between the sexes was a further finding of the systematic review that was of interest to the research team during the development of the testing protocol. Male soccer players had significantly greater distal lower limb linear velocities than females during kicks. This may have allowed them to produce greater ball velocities as the speed of the ball depends on the speed of the foot before impact during a kick (Dörge et al., 2002). In men's rugby, knee joint angular velocity at ball impact is a significant predictor of ball velocity (Sinclair, Taylor, et al., 2014). The researchers had hoped to investigate joint velocity among female kickers using the data collected from the electrogoniometers, but this was not possible due to distortion of results. Use of video footage, 2D manual estimation, and OpenPose for this purpose were limited due to parallax errors introduced by the non-perpendicular angles and the lack of consistency in joint angle results across the three analysis methods. Further investigation into joint velocity in female rugby players would facilitate comparison between the sexes and provide normative data for joint velocities in female athletes. This could be used for training or assessment purposes for elite athletes and their coaches.

6.2.2.4 Kinetics

An interesting finding of the systematic review was the lack of focus on the analysis of kicking kinetics in soccer. Most studies prioritised describing motion through kinematics, rather than evaluating the forces causing this motion. To fully understand kinematic outcomes, kinetics must be explored; however few studies have examined this branch of biomechanics (Atack et al., 2019). Such investigations were of interest to the research team but not within the scope of our project at this time. Future research exploring joint forces, moments, and torques would bolster the significance of kinematic data; knowledge of the mechanisms necessary to produce high performance results would guide coaches, athletic development staff, and players in their training to achieve these outcomes.

6.3 Limitations of the Research Project

6.3.1 Covid-19 Pandemic

When devising the initial protocol for this study in September 2019, I could not have predicted how the next two years would unfold. The onset of the global pandemic in March 2020 led to significant and prolonged restrictions on work, travel, sport, and society. These strict measures were in place for the majority of 2020, as well as from December 2020 until April 2021. As a result of the pandemic, the original protocol was adapted many times, leading to a number of limitations to the study that could not be avoided.

6.3.1.1 Project Timeline

The Covid-19 crisis was extremely limiting for the research team in terms of their ability to fulfil their original timeline for testing. The research project was intended to last a year, including the completion of the systematic review and kicking investigation. Ethical approval was received for the first protocol on 16th January 2020. I carried out pilot testing in the IRFU HPC in early February 2020, with recruitment commencing later that month. Official testing was due to start in March 2020. The ensuing lockdown period constituted Level 5 of the Government's Plan for Living with Covid-19 (Department of the Taoiseach, 2020), with the greatest limitations on personal and professional activities. It was not possible to carry out any in-person testing at any category above Level 3, as sport was not allowed to recommence during these phases. As a result, the project spanned a total of two years to ensure testing could be completed. Despite the gradual easing of government restrictions in mid-2021, we were only able to test players for one day in May, due to the strict protocols and infection prevention control pod systems implemented by the IRFU in their high performance rugby environment.

I was at times frustrated and disheartened by the significant delays and protocol changes that occurred throughout the project. However, the additional time gained as a result of the pandemic had a number of positive outcomes. My co-authors and I were able to carry out a comprehensive systematic review and ensure that it was presented to the highest possible standard. This paper has been accepted for publication in Sports Biomechanics, the Journal of the International Society of Biomechanics in Sport, which is evidence for the benefit of the extended period of work on the document. The delay in official testing also gave the research team the opportunity to carry out a number of pilot trials. This trouble shooting period was helpful to us in highlighting issues with the original testing equipment; it facilitated necessary adaptations to the protocol which would have greatly hindered the logistics of official testing.

6.3.1.2 Recruitment

The recruitment process was a limitation of this study which occurred as a result of the Covid-19 pandemic. The original strategy was to recruit male and female participants from the highest domestic league in Ireland: The All Ireland League. The standard of players across the competitions for men and women are similar, as both are high performing, amateur competitions. This recruitment method would facilitate meaningful comparison between the sexes. Athletes from across the four provinces would be eligible to participate, encouraging a larger sample size and a broader snapshot of kicking biomechanics in players across the county. Due to the breadth of restrictions introduced with the onset of the pandemic, the recruitment pool was narrowed to the Energia Community Series Leinster Conference. Following the cancellation of this league and all domestic competitions, recruitment once again became an issue. The resulting participant sample was one of convenience. Elite female athletes who were available to test in the HPC in early May 2021 were recruited. The original protocol had only considered 15s players; this was broadened to include 7s athletes to ensure adequate testing numbers on the day. It was not possible to recruit any male athletes of an equivalent level during this period, as all were preparing for upcoming competitions at the time. The small, convenience sample size of only one sex was a limitation to this project.

6.3.1.3 Testing Venue

The Covid-19 pandemic also resulted in several changes in testing location. The first protocol included the IRFU HPC as the study venue, which was no longer possible when the site was closed for an extended period during the first Level 5 lockdown. When it reopened, access was strictly limited to staff and players using the facility. The research team adapted the protocol to carry out testing with participants in their individual clubs across Ireland. This too became impractical when travel restrictions remained in place for several months. The narrowing of the recruitment pool to those in the ECS Leinster Conference could have been feasible, but due to delays with equipment, testing could not be carried out before this competition was cancelled. The return to the HPC occurred on short notice but was an unmissable opportunity in the researchers' eyes to ensure that testing could commence. The restrictions in place in this building limited the time that we had to complete their battery of tests, as well as the number of researchers who could access the site. Only two team members could enter the testing venue, which put considerable pressure on myself and my supervisor to perform all aspects of the testing battery. The last minute addition of the video camera, combined with limited manpower, resulted in inaccuracies in the angulation of the footage. We were not as consistent in our positioning of the camera as we could have been, had there been more personnel available and a plan in place for managing the recordings. As a result, some recordings were not to the standard necessary to accurately apply OpenPose Pose Estimation software without introducing parallax errors. This limited the accuracy with which joint centres and angles could be tracked using this software. It also created difficulty when carrying out the protractor method; many of the video clips and resulting frames were not at a 45 degree angle to the kick, which made mapping a 2D analysis onto a 3D movement even more challenging.

6.3.1.4 Equipment

The majority of studies investigating kicking kinematics have been carried out in a laboratory environment with the aim of removing external influences and confounding variables from the analysis. In contrast, we were keen to perform our testing battery in the field. Rugby place kicking is performed under various constraints in a match, which often influence the performance of this skill (C. Pocock, Bezodis, Davids, & North, 2018; Quarrie & Hopkins, 2015). These include the task constraints of the angle and distance to the goal, the environmental constraints of the weather, wind, and pitch, as well as the individual constraints specific to a kicker and the situational constraints dictated by a match scenario (Chris Pocock et al., 2020). The research team aimed to make the kicking assessment as realistic as possible by asking players to perform their kicks in a familiar and meaningful pitch environment. This decision created a number of issues in terms of equipment performance; some of the devices chosen to analyse kicking biomechanics could not cope with the complexities of testing in the field. A number of protocol iterations were developed, and pilot testing was carried out with each piece of equipment to ensure it was fit for purpose prior to official testing. Despite this, several limitations of this study arose as a result of the inability of some testing devices to manage the task and environmental constraints of rugby place kicking in the field.

6.3.1.3.1 Simi Motion Capture Systems

The Simi Motion Capture System was designated as the main biomechanical analysis tool in the first protocol iteration. This 2D system is described by its manufacturers as an efficient, dynamic, and cost effective method of movement analysis (Simi Reality Motion Systems, 2014). It has featured across the spectrum of sports research, including an array of dynamic, high velocity sports such as gymnastics and martial arts (Farana, Uchytil, Zahradnik, & Jandacka, 2015; Reguli, Kalichová, & Zvonár, 2011; Xiao, Hao, Li, Wan, & Shan, 2017), and kicking sports such as soccer (Dicks, Davids, & Button, 2010; Orloff et al., 2008; Scurr & Hall, 2009). This system was made available me through a colleague in the Discipline of Physiotherapy in Trinity College Dublin who had used the Simi Aktysis to much success in a clinical setting.

I carried out pilot testing with the system in the IRFU HPC in March 2020. A number of issues arose during this session. The considerable age of the Simi laptop required it to remain charging at all times which significantly reduced the portability of the device. This was also affected by series of long, cumbersome wires connecting the laptop to the high-speed camera. These challenges were manageable and could have been overcome; however, the main difficulty arose with the testing environment. The indoor pitch in the HPC is enclosed with glass, creating bright reflections in the camera footage. The Simi system relies on the camera's ability to detect the different colours of the LED markers attached to the participants' bodies. The software could not identify the LEDs due to the brightness of the pitch, and so, the system could not track the kickers' movement during the trials. All efforts to adapt the environment and programme set up were to no avail. As a result, other motion capture methods had to be explored. The search for an appropriate alternative was challenging and affected the researchers' ability to proceed with testing in a timely fashion. This was the first indication that viable methods of motion capture analysis in the field are limited.

6.3.1.3.2 Electrogoniometers

Electrogoniometers were chosen to replace the Simi Reality Motion system to record lower limb biomechanics as part of this project. These devices are lightweight, flexible, and portable for use in field testing (Bronner et al., 2010b). They have a high reliability and validity when compared to a digital protractor and motion analysis system (Bronner et al., 2010a, 2010b; Piriyaprasarth et al., 2008; Rowe, Myles, Hillmann, & Hazlewood, 2001) and have been used extensively across biomechanical research in sport and injury management (Chow et al., 2017; Lotfian et al., 2014; Moradi et al., 2014; Thibordeeand & Prasartwuth, 2014). I was able to access the electrogoniometers through members of the research team (FW and CS) who had previously used them to investigate movement biomechanics in sport (Wilson, Gissane, Gormley, & Simms, 2013; Wilson, Simms, Gormley, & Gissane, 2011). FW and I trialled the devices before testing and were optimistic about the use of these devices during the kicking assessment. However, it is clear from the results of the study that the electrogoniometers were not a suitable choice for assessing lower limb kinematics during kicking trials. Anomalies were detected in findings across the board with participants and joints, with the ankle particularly affected. We postulate that the sensors were not robust enough to deal with the ballistic, dynamic nature of kicking because elastic limits of the devices were exceeded by the resultant forces. This was combined with some mild wear and tear to the electrogoniometers, mainly at the hip, due to the positioning of the sensor under the participants' shorts during kicks.

The inaccurate data collected by the electrogoniometers affected the outcome of this project. Two planes of movement were recorded for the hip, knee, and ankle for all participants. Ankle data was removed as we could not process the information in a reasonable way. The majority of results are for the hip and knee, in one plane only, due to background noise affecting the transverse plane. Knee and hip flexion and extension ranges of motion were the most meaningful findings for lower limb kinematics in this project. I had intended to collect data on joint velocity, angular velocity, and displacement; however, this was limited by the poor performance of the electrogoniometers.

The results for a number of participants (P1 and P5-8 for drop kicks and P1-3 and P6-9 in place kicks) had to be dismissed due to the extent of distortion in their kinematic plots. This limited the inter-player comparisons that could be performed, as well as the associations that could be made between the kicking results and demographic data. A significant amount of further analysis was required to ensure that some meaningful information could be extracted from the kicking assessments. The results of this study were extremely limited by the inability of the electrogoniometers to withstand the forces applied to them during the assessment. As such, a main finding of this project is that electrogoniometers are not sufficiently robust to manage the dynamic and ballistic nature of kicking. The researcher team would not support the use of these devices in recording kinematic data during high speed, high force activities.

6.3.1.3.3 OpenPose Pose Estimation

The OpenPose pose estimation software became available to the research team through engineering colleague, RN, and offered a prime opportunity for inter-disciplinary research collaboration. This is one of the most popular and easy to use open source pose estimation programmes (Cao, Simon, Wei, & Sheikh, 2017; Nakano et al., 2020). In the plan for the second protocol, it was intended that three high speed GoPro Hero cameras would be used to record footage of the kicking trials from three different angles. The cameras would be operated by engineering members of the research team and synced and calibrated using a checkerboard. OpenPose would be applied to the videos from the three angles around the kicker to create a 3D estimation of the participant's movements. When permission to use the HPC was granted on short notice, the protocol for testing was amended again. Due to lack of personnel and an inability to access the camera equipment in the limited time frame, we decided to proceed with testing without collecting video footage. An IRFU camera was made available to us on the day of the assessments. I endeavoured to manage the full electrogoniometer and kicking protocol, as well as control the position of the camera, with the latter falling victim to inaccuracy. The camera was not precisely or consistently placed at a 45° angle to the kicker. When OpenPose was being applied to this footage, parallax errors were introduced by the inappropriate recording angles. Given that only one angle of video footage was recorded for each kick, 3D pose estimation could not be performed. The subsequent 2D estimation carried out on substandard footage may have limited the accuracy of the OpenPose results.

6.3.1.3.4 Protractor Method

Following the kinematic analyses carried out using the electrogoniometers and pose estimation, there was still considerable variation in the joint range of motion results. I was unsure which, if either, of these methods was providing accurate outcomes. To gain some clinical perspective on this, my fellow researchers and I carried out a qualitative screening of the data. The research team consists of physiotherapists and engineers who have considerable experience and understanding of sports biomechanics and human movement patterns. We provided subjective opinions on whether the results obtained by the two analyses methods above were feasible during a kicking motion. To add an objective element to this review, a 2D manual angle measurement technique was applied. Still frames from the video footage were entered into PowerPoint and joint centres and lines were mapped onto the images by RN and me. The resulting angles were mapped onto a protractor image to give an approximate value for the range of motion at that key point.

This crude method was time-consuming. Judgement of joint centres and lines of movement from a 2D image was challenging due to the multiplanar nature of kicking; thus, this process was subjective to each analyst. This, combined with the inherent inaccuracies of performing such analysis by hand, may have introduced a significant degree of inaccuracies into these results. The researchers were well aware of this issue before undertaking this process, however, it was deemed necessary in this instance to provide a numerical reference to the subjective qualitative analysis of kicks by the research team.

Overall, the methods and findings of this research study were negatively impacted by the Covid-19 pandemic and challenges presented by the testing equipment.

6.4 Implications and Recommendations for Future Research

6.4.1 Learning from this Project

Considerable learnings have been gained through undertaking this project. The systematic review was carried out to compare the kinematics and kinetics of kicking in male and female athletes in field-based sports. Biomechanical differences between the sexes were identified in soccer, including variations in ball velocity, distal lower limb velocity, and ankle and trunk range of motion. A key finding of this review was the dearth of research into biomechanics in women's sport. Only soccer could be included due to the lack of relevant research in any other field-based kicking sports. This knowledge gap is a prime opportunity for further exploration; one that should be acted upon to meet the demands of the spectrum of rapidly developing women's sports.

Over the course of the project, the goals for our own study changed drastically as a result of the global pandemic. The original protocol aimed to investigate hip and groin health and kicking biomechanics in female AIL rugby players, compared to their male counterparts. The final iteration endeavoured to develop and evaluate a study protocol designed to explore the kicking kinematics of elite female rugby players. From the aforementioned limitations, it is clear that the final protocol tested as part of this project was not as robust as I had intended. Through reflection on the process, I have gained a strong understanding of the avoidable and unavoidable errors, mistakes, and shortcomings that occurred and how to prevent them going forward. This pilot study was beneficial in allowing my colleagues and I to gain some insight into kicking kinematics in female rugby players, while testing the feasibility and reliability of the protocol. My aim going forward is to apply for funding to carry out further investigations into the biomechanics of kicking in women's rugby, with the learnings gained through this project as a foundation for development of a robust and comprehensive protocol. As women's rugby continues to grow, it is imperative that research keeps pace. To ensure that this growth is safe and sustainable, training and athletic development for female athletes must be driven by female-specific research.

6.4.2 Investigating Kicking Biomechanics in Female Rugby Players

The pilot study conducted as part of this project was the first of its kind to exploring the biomechanics of kicking in women's rugby. This area remains untapped in terms of research opportunities; as such, studies of all types are necessary to build a foundation from which further research can be built. Based the learnings gained from this process, I have a number of recommendations on the rigorous study methods necessary to explore this skill further and I am keen to be involved in this process.

The original protocol outlined for this study in Chapter 3 is comprehensive. Covid-19 related restrictions limited our ability to complete this plan. However, as Ireland progresses through its Living with Covid-19 plan (Department of the Taoiseach, 2021), it is likely that this procedure could be implemented safely in the near future. I believe the methods described in this chapter are robust, and with some equipment adaptations, undertaking this study procedure would provide pioneering evidence on hip and groin health and kicking biomechanics in women's rugby.

I recommend carrying out this research with high performance athletes. In Ireland, the national and provincial men's teams are professional, while the women's equivalents remain amateur. Meaningful comparison between these groups is challenging, given the extensive differences in training, coaching, schedules, and external commitments for men and women. As such, recruitment of high performing amateur domestic athletes affords the best opportunity to investigate differences between the sexes in a more meaningful way. The AIL is the highest level of competition for players falling into this category in Ireland. It is a national league, incorporating the best teams across the country. Recruitment of kickers from these clubs would facilitate the inclusion of a broad spectrum of athletes with varying playing and coaching experiences.

The testing venue used for further research depends on the aims of the study. The majority of research studies investigating kicking biomechanics in field-based sports are carried out in a laboratory setting. This is a highly controlled environment with minimal external constraints or influences, which allows researchers to design their study to the finest detail and manipulate all associated variables. However, given the impact of external influences on kicking performance in a match scenario, such investigations may have limited application in a live rugby scenario. As such, I would advocate for biomechanical testing in the field. Performing their assessments on a pitch surface, wearing their rugby boots, and aiming towards goal posts simulates an athlete's normal kicking environment and may result in a more accurate representation of their movement biomechanics during this skill. The IRFU HPC is a prime location to undertake this testing, as the indoor pitch provides a realistic surface for the kicking assessments, and there is ample clinical space to facilitate other aspects of the study.

The hip and groin assessments outlined as part this protocol are an important addition to the testing battery. While not explored as part of this pilot, I support further investigation in this area as part of future kicking research. Hip and groin injuries are prevalent in kicking athletes and rugby players, however, there is no published research setting this scene in women's rugby. The literature supports exploring patient-reported hip and groin health using the HAGOs (Thorborg, Hölmich, Christensen, Petersen, & Roos, 2011), and investigating objective measures using a manual goniometer for range of motion (Nussbaumer et al., 2010), a ForceFrame or handheld dynamometer for hip strength (Breen, Farrell, & Delahunt, 2021; Thorborg, Petersen, Magnusson, & Hölmich, 2010), and a NordBord for hamstring strength (Ogborn et al., 2021).

The findings of this project highlight the importance of selecting the most appropriate equipment to investigate movement biomechanics during kicks. Optoelectronic measurement systems are considered the gold standard of movement analysis (Corazza, Mündermann, Gambaretto, Ferrigno, & Andriacchi, 2009; Springer & Yogev Seligmann, 2016). They are frequently used across the literature to evaluate the 3D mechanics of kicking and have featured in a number of rugby studies (Atack et al., 2017, 2019; Bezodis et al., 2007), as well as several papers from our systematic review (Katis et al., 2014; Katis et al., 2015; Navandar et al., 2016, 2017; Navandar et al., 2018). The benefits of the high degree of accuracy in these systems is counteracted by several limitations. Use of this equipment is restricted to a laboratory environment, due to its complex set-up and thus, does not simulate the constraints of pitch-based kicking. Optoelectronic systems can only capture data within a small area, which reduces the capacity of the equipment to record kicking outcomes in a sport such as rugby, where place kicks can be taken from any location on the pitch (Quarrie & Hopkins, 2015). The cost of acquiring such equipment may be a limiting factor for future studies, as it was beyond the capabilities of this research team.

For field-based testing, the popularity of wearable inertial sensor measurement systems (IMUs) has increased in recent years. These devices consist of a combination of 3D accelerometers, gyroscopes, and magnetometers; they are attached to the body to provide kinematic and kinetic data, and determine the 3D position and global orientation of different segments (van der Kruk & Reijne, 2018). IMUs are well suited to testing in a realistic environment as they are easy to use, non-invasive, and the most portable of all measurement systems (Lee, Burkett, Thiel, & James, 2011). Research exploring the application of inertial sensors to rugby activities indicates a high level of accuracy for detecting collisions, carries, tackles, rucks, and scrums (Chambers, Gabbett, & Cole; Chambers et al., 2019; MacLeod, Hagan, Egaña, Davis, & Drake, 2018).

A study by Blair, Duthie, Robertson, Hopkins, and Ball (2018) investigated the concurrent validity of an inertial system (XSens MVN) for measuring lower limb kinematics during kicking compared to an optoelectronic measurement system (Vicon Nexus v2). Four football codes were included (Australian Football, soccer, rugby league, and rugby union), with participants performing kicks specific to their codes. The XSens equipment was found to have good concurrent validity when measuring high velocity movement such as those involved in sport-specific settings, as similar results were achieved in both. I am interested in exploring the use of this technology to carry out further research into kicking in women's rugby. There appear to be numerous benefits to the XSens devices, including their portability, ease of set-up, lack of markers, wide measurement range, quick data output, and the ability to carry out realistic field-based testing (Blair et al., 2018; Roetenberg, Luinge, & Slycke, 2009). I am currently evaluating funding opportunities with the aim of investing in this equipment for future research ventures.

As the first study of its kind to explore kicking biomechanics in women's rugby, there were many hurdles to overcome and lessons to learn throughout this project. The study protocols were planned, developed, and amended constantly, both due to the unfolding Covid-19 crisis, and the difficulties encountered with equipment along the way. As such, the recommendations outlined above are based on considerable review of the literature, pilot testing, and troubleshooting. I am confident that future studies will benefit from the learnings gained from this process. It is hoped that this project will form the foundation for more comprehensive, robust investigations into the biomechanics of kicking in women's rugby going forward.

6.5 Research Project Summary

This project was undertaken to bridge the gap in the literature exploring kicking kinematics in women's rugby. A systematic review and meta-analysis comparing kicking biomechanics in male and female athletes in field-based sport was completed to form the foundation for our research study. The findings of this review highlighted differences between the sexes in the kinematics and kinetics of this skill in soccer. Men produced significantly greater ball velocities and distal lower limb velocities than women. Greater hip and knee torques, ball-to-foot velocity ratios, and ankle plantarflexion angles were a feature of kicks performed by male athletes, while women exhibited greater trunk flexion angles than men. Skilled players generated power using tension arcs; a technique not seen in novices. This indicates that skill level within sex may have a greater influence on kicking performance than differences between the sexes. The fact that only soccer could be included in this review highlights the need for further research investigating kicking performance in both sexes across the spectrum of sports.

Based on these results, I developed a study protocol which aimed to investigate the kicking kinematics and hip and groin health of high performing amateur female rugby players, compared to their male counterparts. The assessment battery consisted of a clinical hip and groin examination and a two-dimensional analysis of kicking. Pilot testing had been completed and recruitment was due to commence when the Covid-19 pandemic was declared in March 2020.

As a result of the ensuing global health crisis, this project was subject to significant delays and challenges. The original protocol and its objectives were adapted many times in an effort to ensure testing could be carried out in a safe, feasible manner.

The final protocol was implemented in May 2021 in the IRFU HPC. A total of nine elite female rugby players were recruited from the Ireland XVs and 7s teams and asked to perform a series of place and drop kicks on goal in the HPC indoor pitch. Kicking kinematics were recorded using a high speed camera and three electrogoniometers attached to the hip, knee, and ankle of the kicking leg. Analysis of the electrogoniometer results revealed significant distortion to the data, indicating that these devices are not robust enough to cope with the demands of field-based biomechanical analysis of kicking. Pose estimation software and a manual protractor method were used to validate the results. During place kicks, a mean maximal hip extension angle of -26.25 ± 18.31°, knee flexion angle of 102.73 ± 1.66°, and hip flexion angle of 110 ± 22.92° were used by female rugby players. Drop kicks were performed with a mean maximum knee flexion angle of 105.91 ± 12.86° and a maximal hip flexion angle of 91.48 ± 26.2°.

While this project had a number of limitations, I am confident that significant learning can be gained from the process. The original protocol developed to explore hip and groin health and kicking biomechanics in female rugby players compared to their male counterparts is comprehensive. Implementing this procedure using inertial sensors to record kicking biomechanics would provide important insight into kicking in women's rugby. Future study in this area is greatly needed to enhance performance of this skill in female athletes and inform injury prevention strategies. As the game progresses, and skills, standards, and support improve, investment of time and resources into research in women's rugby is necessary to shape the future of the game and ensure its sustainable and safe development. I am eager to build on the learnings from this project to produce a more robust study into women's kicking biomechanics.

CHAPTER 7:

APPENDICES

APPENDIX 1: Systematic Review Oral Presentation, Women in Sport and Exercise Conference 2021, University of Worchester, 19th-22nd April 2021

Figure 1. Conference Abstract.

It's not all about power: A systematic review and meta-analysis comparing kicking biomechanics in male and female athletes in field-based sports

Molly Boyne[1], Ciaran Simms[2], Nicol van Dyk[3], Garreth Farrell[4], Emmet Farrell[4], Cliodhna McHugh[1], Julia Wall[1], David Mockler[5], Fiona Wilson[1]
[1]Discipline of Physiotherapy, School of Medicine, Trinity College Dublin, Dublin, Ireland; [2]Department of Mechanical and Manufacturing Engineering, Trinity College Dublin, Dublin, Ireland; [3]High Performance Unit, Irish Rugby Football Union, Dublin, Ireland; [4]Leinster Rugby, Dublin, Ireland; [5]John Stearne Library, Trinity College Dublin, Dublin, Ireland

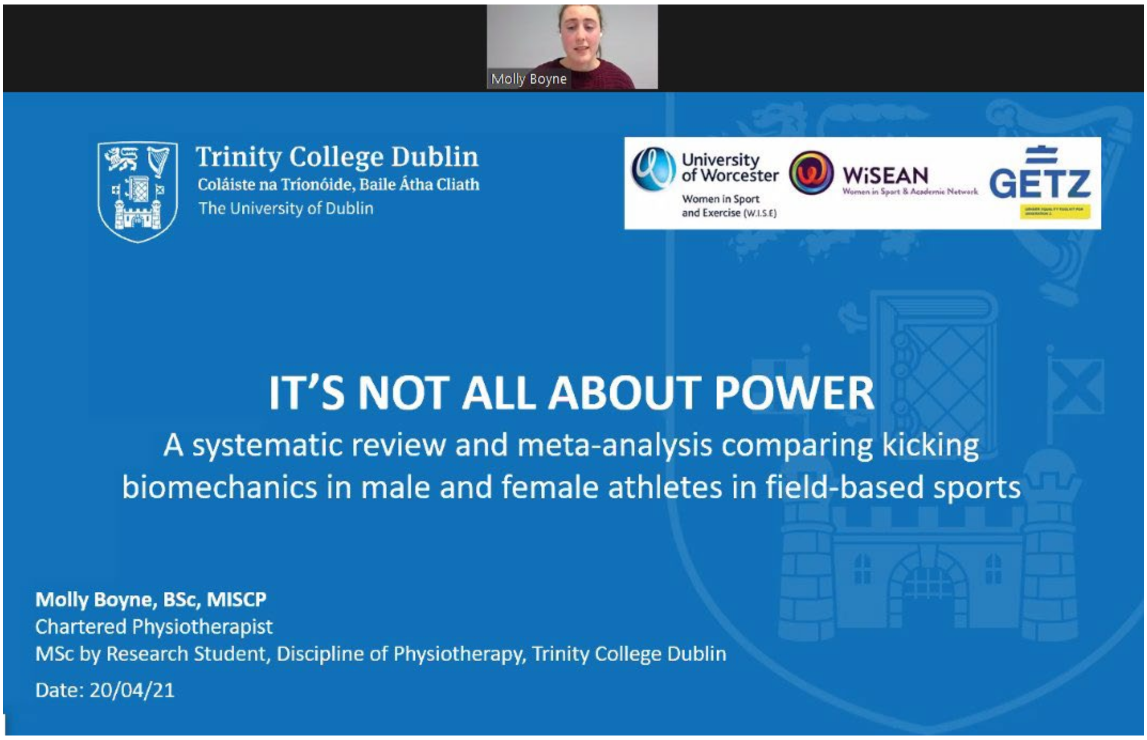
Kicking is a fundamental action in many field-based sports. Understanding the mechanism by which athletes produce optimal kicks is important for performance and injury prevention. Most studies investigating kicking have been conducted with male athletes, despite the recent exponential growth in women's sport. This has resulted in a dearth of specific data to inform the coaching of this skill in females. The aim of this systematic review was to compare the kicking biomechanics of male and female athletes in field-based sports. As per PRISMA guidelines, articles were retrieved from searches across five online databases. Studies investigating kicking biomechanics in field-based athletes of both sexes were eligible for inclusion. Articles were screened using Covidence and data extracted based on STROBE recommendations. Methodological quality was assessed using the AXIS Tool. The review yielded 23 studies, featuring 455 soccer players. Male athletes produced significantly greater peak ball velocities (mean difference (MD) 4.32m/s) and linear velocities of the ankle (MD 2.02m/s), foot (MD 1.60m/s), and toe (MD 2.79m/s) during kicks than females. Women exhibited greater trunk flexion range of motion, as well as decreased ankle plantarflexion at ball contact and peak distal joint velocities compared to males. The findings of this review indicate that variations in kicking biomechanics between the sexes are caused by differences, not only in power, but in technique. This paper highlights the need to redress the balance of research in this area by investigating kicking performance in female athletes across the spectrum of sports to inform women-specific coaching programmes.

Figure 2. Conference Presentation Schedule

Day 2: Tuesday 20th April 2021

Time	Sessions – All times are UK (BST)	
	Session 3a – Sporting Inclusion (Oral Presentations) **Chair: Dr Rachael Bullingham**	**Session 3b – Performance Analysis (Oral Presentations)** **Chair: Gareth Jones**
13.00 – 14.00	Beyond the bottom line? Gender, branding and the Australia/New Zealand AsOne 2023 bid strategy for the 2023 FIFA Women's World Cup – Dr Verity Postlethwaite Evaluating the impact of inclusive sporting opportunities for disabled individuals within Wales – Rachael A. Newport Women's cycling in Qatar – Dr Thomas Ross Griffin	Side-to-side asymmetry of single-leg repeated deceleration-acceleration performance is related to deterioration of running change-of-direction performance in amateur adult female netball players – Dr Nicholas C. Clark Locomotor effort: An observational study in elite women's rugby 7s – Bethany Smith It's not all about power: A systematic review and meta-analysis comparing kicking biomechanics in male and female athletes in field-based sports – Molly Boyne

Figure 3. Conference Presentation Introductory Slide



APPENDIX 2: Systematic Review Poster Presentation, the Female Athlete Conference, Boston Children's Hospital, 10-12th June 2021

IT'S NOT ALL ABOUT POWER!

A systematic review and meta-analysis comparing kicking biomechanics in male and female athletes in field-based sports

Molly Boyne[1], Ciaran Simms[2], Nicol van Dyk[3], Garreth Farrell[4], Emmet Farrell[4], Cliodhna McHugh[1], Julia Wall[1], David Mockler[5], and Fiona Wilson[1]

[1]Discipline of Physiotherapy, School of Medicine, Trinity College Dublin, Dublin, Ireland; [2]Department of Mechanical and Manufacturing Engineering, Trinity College Dublin, Dublin, Ireland; [3]High Performance Unit, Irish Rugby Football Union, Dublin, Ireland; [4]Leinster Rugby, Dublin, Ireland; [5]John Stearne Library, Trinity College Dublin, Dublin, Ireland.

Introduction

Kicking is a fundamental skill in many field-based sports. Understanding the mechanism by which athletes produce optimal kicks is important for performance and health. Most research investigating kicking biomechanics has been carried out on male athletes, despite the recent exponential growth in women's sport. As a result, most coaching advice and injury prevention strategies provided to female players are based solely on data collected from males. This fails to account for the anthropometric and physiological differences between the sexes, and may prevent female athletes from achieving peak performance.

Aims

1. Compare the kinematics and kinetics of kicking in male and female athletes in field-based sports.
2. Establish specific characteristics associated with kicking techniques in men and women.

Methods

Protocol:
- Developed based on the PRISMA recommendations.
- Registered online with Prospero.

Search strategy:
- Created with the assistance of a medical librarian.
- Carried out across five databases (EMBASE, Medline (OVID), Web of Science, SCOPUS, Engineering Village) and the grey literature.

Study screening:
- Studies investigating kicking biomechanics in male and female athletes competing in field-based sports were eligible for inclusion.
- Title, abstract, and full text screening carried out by two reviewers using Covidence.

Data extraction:
- Conducted by one reviewer based on the STROBE guidelines.

Risk of bias assessment:
- Performed by two reviewers using the AXIS Tool.

Data analysis:
- Random effects meta-analysis performed with RevMan software.

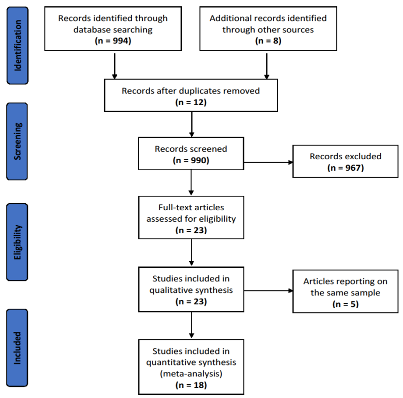
Results

This systematic review included a total of 18 studies (Figure 1), featuring:
- 455 participants: 226 males and 229 females.
- 2 sports: soccer and indoor football.

Methodological quality ranged from moderate to very poor.

Results

Figure 1: PRISMA Flowchart



Findings were described under two sub-areas of biomechanics: kinematics and kinetics.

Kinematics

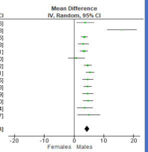
Velocities

Men produced significantly greater ball velocity than women (P<0.0001) (Figure 2).

Figure 2: Ball velocity meta-analysis forest plot

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Barfield et al. (2002)	25.3	1.51	2	21.5	2.44	6	4.8%	3.80 [0.94, 6.66]
Chanda and Mondal (2018)	42.82	7.28	10	26.78	3.03	10	2.3%	16.04 [11.15, 20.93]
Katis et al. (2014)	21.39	1.6	10	17.89	0.56	10	10.1%	3.50 [2.45, 4.55]
Katis et al. (2015)	21.5	2.01	10	18.41	1.95	10	7.8%	3.09 [1.35, 4.83]
Navandar et al. 3 (2018)	28.63	1.75	19	25.25	2.47	26	9.5%	3.38 [2.15, 4.61]
Orloff et al. (2008)	22.7	3.1	11	21.9	3.5	12	5.2%	0.80 [-1.90, 3.50]
Sakamoto et al. (2010)	26.6	1.6	17	22	2	17	9.5%	4.60 [3.38, 5.82]
Sakamoto et al. (2016)	27.9	1.3	6	22.5	1	6	9.2%	5.40 [4.09, 6.71]
Sakamoto et al. 1, 2, 3 (2011, 2012, 2013)	26.6	2.6	17	22	2.6	17	7.8%	4.60 [2.85, 6.35]
Sakamoto et al. A, B (2013, 2014)	26.6	2	13	22	1.4	13	9.1%	4.60 [3.27, 5.93]
Shan (2009)	24.2	3.1	22	19.6	2.6	22	7.9%	4.60 [2.91, 6.29]
Shan et al. (2012)	24.5	3.3	24	19.8	2.8	26	7.9%	4.70 [3.00, 6.40]
Smith and Gilleard (2016)	23.85	3.02	6	20.28	1.2	7	5.5%	3.57 [1.00, 6.14]
Tant et al. (1991)	21.15	4.4	8	16.17	2.8	7	3.5%	4.98 [1.29, 8.67]
Total (95% CI)			175			189	100.0%	4.32 [3.50, 5.13]

Heterogeneity: $Tau^2 = 1.42$; $Chi^2 = 38.82$, df = 13 (P = 0.0002); $I^2 = 67\%$
Test for overall effect: Z = 10.40 (P < 0.00001)



Men had significantly greater peak linear velocities at the distal joints of the toe (P<0.0001), foot (P=0.005), and ankle (P<0.003).

Differences between the sexes were less significant proximally at the knee joint (P<0.003) and insignificant at the hip joint (P=0.11).

Range of motion

Male athletes:
- Significantly greater ankle plantarflexion angles at ball contact - this rigid position allowed them to apply more force to the ball.
- Greater knee flexion angles before and at ball contact.

Female athletes:
- Significantly greater trunk forward and side flexion ranges during the follow-through phase to slow their forward momentum.
- Greater range of knee flexion during follow-through phase.
- Greater support leg peak hip extension and abduction ranges.

Kinetics

Both male and female athletes used a proximal-to-distal sequence of lower limb movement during kicks.

Men had significantly greater:
- Peak knee and hip joint torques
- Thigh-to-shank energy transfers
- Ball-to-foot velocity ratios

Skilled vs novice players

Skilled men and women created tension arcs to generate kicking power using shoulder, hip, and trunk movement.
- Range of motion to achieve this greater in males than females.
- Except trunk flexion - skilled female range of motion x5 greater.
- This technique was not used by novice players.

Skilled players produced higher velocity kicks than novices.

Summary

Conclusion: Variations in kicking biomechanics between male and female kickers are caused by differences in both power and technique.

APPENDIX 3: Systematic Review Search Strategy

A systematic search strategy was created for this review with the assistance of the medical librarian in Trinity College Dublin. Five online databases were searched: EMBASE, Medline, Web of Science, SCOPUS, and Engineering Village.

The search terms were adapted for each database, as outlined below:

EMBASE

'leg movement'/exp

Kick*:ab,ti

#1 OR #2

'soccer'/exp OR 'football'/exp OR 'rugby'/exp OR 'soccer player'/exp OR 'football player'/exp

(soccer OR rugby OR football*):ab,ti

#4 OR #5

#3 AND #6

'conference abstract':it OR 'conference review':it

#7 NOT #8

Medline (OVID)

Kick*.ti,ab.

Soccer/ OR football/

(soccer OR rugby OR football*).ti,ab.

or/2-3

and/1,4

Web of Science

TS=(Kick* AND (soccer OR rugby OR football*) AND kinematic*)

SCOPUS

TITLE-ABS(Kick* AND (soccer OR rugby OR football*) AND kinematic*)

Engineering Village

(((Kick* AND (soccer OR rugby OR football*))) WN KY)

APPENDIX 4: Systematic Review Study Reporting Explanation

The search and screening process yielded a total of 23 articles to be included in the systematic review. These studies were produced by 13 authors, two of whom were the primary investigators in multiple papers (Archit Navandar and Keiko Sakamoto). The articles published by Navandar and colleagues (Navandar et al., 2016, 2017; Navandar et al., 2018) are based on research conducted as part of his doctoral degree. As such, they feature the same participants, with the same demographics and some of the same results. To avoid double reporting of data, the results of these papers are reported as being from the same study. Similarly, Sakamoto and colleagues produced seven papers featured in this review. Of these, three appear to discuss one study, sharing the same number of participants, demographic data, and some results (Sakamoto & Asai, 2013; Sakamoto et al., 2011; Sakamoto et al., 2012), while a further two articles seem to report on another study (Sakamoto et al., 2014; Sakamoto et al., 2013). Attempts to contact the author for further information were unsuccessful. For the purpose of this review, articles with the same participant pool are discussed as one study and their common demographic data and results only reported once. Therefore, a revised total of 18 studies are featured in this review.

APPENDIX 5: Systematic Review Participant Demographic Information Table

Author	No. of participants			Age (years)		Body weight (kg)		Height (cm)	
	Total	Males	Females	Males	Females	Males	Females	Males	Females
Tant et al. (1991)	15	8	7	20.7 ± 1.1	20.1 ± 1.5	72.2 ± 3	61.1 ± 2.8	176.4 ± 2.3	151.8 ± 3.3
Barfield et al. (2002)	8	2	6	19-22	19-22	87.32	60.1	184.15	164.25
Orloff et al. (2008)	23	11	12	20.2 ± 1.2	20.2 ± 1.2				
Cramer (2009)	20	10	10						
Shan (2009)	44	22 NP: 11 SP: 11	22 NP: 11 SP: 113	21.7 ± 2.2	21.7 ± 2.2	NP: 72.4 ± 2.7 SP: 72.6 ± 2.3	NP: 66.3 ± 1.9 SP: 67.1 ± 2.0	NP: 1.75 ± 0.05 SP: 1.76 ± 0.04	NP: 1.65 ± 0.03 SP: 1.68 ± 0.04
R. H. Brophy et al. (2010)	25	13	12	19.8 ± 1.6	19.4 ± 1.4	75.0 ± 8.8	63.0 ± 8.7	178.6 ± 8.1	166.1 ± 8.0
Gheidi and Sadeghi (2010)	14	7	7	23 ± 1.7	23 ± 2.4	72.4 ± 4.04	53.7 ± 4.33	182.2 ± 4.73	160.7 ± 4.84
Sakamoto et al. (2010)	34	17	17						
Sakamoto et al. (2011)	34	17	17			65.7 ± 4.8	56.0 ± 3.4	172.0 ± 4.4	161.4 ± 4.5
Sakamoto et al. (2012)	34	17	17			65.7 ± 4.8	56.0 ± 3.4	172.0 ± 4.4	161.4 ± 4.5
Sakamoto and Asai (2013)	34	17	17			65.7 ± 4.8	56.0 ± 3.4	172.0 ± 4.4	161.4 ± 4.5
Gonzalez-Jurado et al. (2012)	22	11	11	17-19	17-19				
Shan et al. (2012)	50	24	26	21.7 ± 2.2	21.7 ± 2.2	NP: 72.4 ± 2.7 SP: 72.6 ± 2.3	NP: 66.3 ± 1.9 SP: 67.1 ± 2.0	NP: 1.75 ± 0.05 SP: 1.76 ± 0.04	NP: 1.65 ± 0.03 SP: 1.68 ± 0.04
Sakamoto et al. (2013)	26	13	13			66.8 ± 4.9	57.1 ± 5.7	174.3 ± 4.7	160.4 ± 4.9
Sakamoto et al. (2014)	26	13	13			66.8 ± 4.9	57.1 ± 5.7	174.3 ± 4.7	160.4 ± 4.9
Katis et al. (2014)	20	10	10	26.3 ± 4.9	24.4 ± 4.2	81.3 ± 8.1	61.8 ± 5.1	178.1 ± 5.1	169.7 ± 5.7
Katis et al. (2015)	30	A: 10 P: 10	10	A: 25.3 ± 4.9 P: 15.1 ± 0.7	24.9 ± 3.5	A: 80.8 ± 6.4 P: 47.1 ± 13.2	62.2 ± 3.7	A: 179 ± 4.6 P: 143.2 ± 35.2	167.4 ± 4.2
Navandar et al. (2016)	45	19	26						

Navandar et al. (2017)	45	19	26	21.6 ± 2.0	22.15 ± 4.5	71.46 ± 6.22	60.71 ± 9.48		
Navandar et al. (2018)	45	19	26	21.6 ± 2.0	22.15 ± 4.5	71.46 ± 6.22	60.71 ± 9.48		
Sakamoto et al. (2016)	12	6	6			66.4 ± 6.8	58.0 ± 6.8	175.0 ± 5.8	158.7 ± 6.7
Smith and Gilleard (2016)	13	6	7	22.3 ± 3.4	25.3 ± 7.6	81.9 ± 10.8	68.5 ± 9.7	182.0 ± 4.0	164.8 ± 4.8
Chanda and Mondal (2018)	20	10	10	16-22	16-22				

Full abbreviation list: No. – number; 1st – first trial; 2nd – second trial; 3rd – third trial; Instep – kick performed with the instep/superior portion of the foot; Inside – type of kick performed with the inside/medial border of the foot; Side-foot – type of kick performed with the inside/medial border of the foot; In-front – type of kick performed with the supero-medial border of the foot, between the instep and inside aspects; LD – low drive kick; HD – high drive kick; MD – maximum drive kick; DL – dominant leg; NDL – non-dominant leg; SL – support leg; Pre-F – pre-fatigue kicking trials performed before a fatigue protocol was implemented with participants; Post-F – post-fatigue kicking trials performed after a fatigue protocol was implemented with participants; NP – novice player; SP – skilled player; A – adult male; P – pre-pubertal male; I – players with a history of hamstring injury; UI – uninjured players with no history of hamstring injury; S – successful kick trials that hit the assigned target; US – unsuccessful kick trials that did not hit the assigned target; Impact – the point of foot impact with the ball; GC – ground contact; BC – ball contact; FT – follow-through; ROM – range of motion; Flx – flexion; Ext – extension; Abd – abduction; Add – adduction; Ant – anterior; Post – posterior; DF – dorsiflexion; PF – plantarflexion; IR – internal rotation; ER – external rotation; In/eversion – inversion/eversion; Min – minimum; Max – maximum; COG – centre of gravity; Nm – Newton-meter; Nm/kg - Newton-meter per kilogram; Rad/s – radians per second is the SI unit of angular velocity.

APPENDIX 6: Systematic Review Ball Velocity Results Tables

Mean Ball Velocity Results Table

Author	Males (m/s)	Females (m/s)
Sakamoto et al. (2010)	Instep: 26.6 ± 1.6 In-front: 26.6 ± 1.6 Inside: 21.9 ± 1.4	Instep: 22.0 ± 2.0 In-front: 21.3 ± 2.5 Inside: 18.3 ± 1.6
Sakamoto et al. (2011) Sakamoto et al. (2012) Sakamoto and Asai (2013)	Instep: 26.6 ± 2.6 Inside: 21.9 ± 2.0	Instep: 22.0 ± 2.6 Inside: 19.0 ± 2.1
Sakamoto et al. (2013) Sakamoto et al. (2014)	26.6 ± 2.0	22.0 ± 1.4
Sakamoto et al. (2016)	Instep: 27.9 ± 1.3 Side-foot: 26.9 ± 1.3	Instep: 22.5 ± 1.0 Side-foot: 21.5 ± 1.0
Chanda and Mondal (2018)	4282.30 ± 727.85 cm/sec	2677.60 ± 302.83 cm/sec

Peak Ball Velocity Results Table

Author	Males (m/s)	Females (m/s)
Katis et al. (2014)	Pre-F: 1st: 21.50 ± 2.01 2nd: 21.14 ± 1.74 3rd: 21.39 ± 1.60 Post-F: 1st: 18.99 ± 1.81 2nd: 19.86 ± 2.06 3rd: 19.96 ± 2.66	Pre-F: 1st: 18.41 ± 1.55 2nd: 18.03 ± 0.73 3rd: 17.69 ± 0.56 Post-F: 1st: 15.77 ± 1.82 2nd: 16.44 ± 2.20 3rd: 17.46 ± 2.12
Katis et al. (2015)	A: 21.50 ± 2.01 P: 19.44 ± 1.88	18.41 ± 1.95
Navandar et al. (2016)	DL: 28.53 ± 1.61 NDL: 26.11 ± 2.71	DL: 25.0 ± 2.47 NDL: 22.36 ± 2.68
Navandar et al. (2017) Navandar et al. (2018)	DL: I: 28.00 ± 0.00 UI: 28.63 ± 1.75 NDL: I: 27.00 ± UI: 26.06 ± 2.78	DL: I: 24.17 ± 2.48 UI: 25.25 ± 2.47 NDL: I: 23.25 ± 1.26 UI: 22.19 ± 2.86

Instantaneous Post-Impact Ball Velocity Results Table

Author	Males (m/s)	Females (m/s)
Tant et al. (1991)	LD: 21.17 ± 2.3 HD: 14.14 ± 4 MD: 21.15 ± 4.4	LD: 17.01 ± 3.5 HD: 13.51 ± 6.6 MD: 16.17 ± 2.8
Barfield et al. (2002)	DL: 25.3 ± 1.51 NDL: 23.6 ± 1.57	DL: 21.5 ± 2.44 NDL: 18.9 ± 2.05
Orloff et al. (2008)	22.7 ± 3.1	21.9 ± 3.5
Shan (2009)	NP: 16.9 ± 2.7 SP: 24.2 ± 3.1	NP: 13.2 ± 2.3 SP: 19.6 ± 2.6
Shan et al. (2012)	NP: 17.2 ± 2.9 SP: 24.5 ± 3.3	NP: 13.2 ± 2.3 SP: 19.8 ± 2.8
Smith and Gilleard (2016)	23.85 ± 3.02	20.28 ± 1.20

APPENDIX 7: Systematic Review Linear Joint Velocity Results Table

Author	Ankle (m/s)		Knee (m/s)		Hip (m/s)		Toe (m/s)		Foot (m/s)	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Sakamoto et al. (2010)										Instep: 19.3 ± 2.1 In-front: 8.6 ± 2.2 Inside: 15.3 ± 1.1
Sakamoto et al. (2011), Sakamoto et al. (2012) Sakamoto and Asai (2013)									Instep: 20.5 ± 2.2 Inside: 15.6 ± 1.4	Instep: 18.0 ± 1.8 Inside: 14.0 ± 1.3
Barfield et al. (2002)	At impact: DL: 13.8 ± 1.0 NDL: 12.2 ± 0.9	At impact: DL: 11.9 ± 1.1 NDL: 9.9 ± 1.2					Peak: DL: 20.4 ± 1.3 NDL:18.5 ± 1.6 At impact: DL: 18.9 ± 1.6 NDL:17.7 ± 1.2 Mean: DL: 13.9 ± 1.1 NDL:12.9 ± 1.1	Peak: DL: 18.7 ± 2.9 NDL: 16.2 ± 2.5 At impact: DL: 16.2 ± 2.3 NDL: 14.8 ± -2.1 Mean: DL: 13.5 ± 2.1 NDL: 12.2 ± 1.8		

Gheidi and Sadeghi (2010)	At impact: S: 14.62 ± 1.5 US: 16.88 ± 1.61 Peak: S: 16.62 ± 1.90 US: 17.38 ± 1.75	At impact: S: 11.86 ± 1.32 US: 12.10 ± 1.50 Peak: S: 11.86 ± 1.33 US: 12.94 ± 1.62	At impact: S: 3.58 ± 0.87 US: 4.04 ± 1.08 Peak: S: 7.44 ± 0.76 US: 8.06 ± 0.93	At impact: S: 0.40 ± 0.98 US: 4.06 ± 1.2 Peak: S: 7.04 ± 0.6 US: 7.42 ± 0.82	At impact: S: 14.62 ± 1. US: 16.88 ± 1.61 Peak: S: 16.62 ± 1.9 US: 17.38 ± 1.75	At impact: S: 11.86 ± 1.32 US: 12.1 ± 1.5 Peak: S: 18.86 ± 1.33 US: 12.94 ± 1.62	At impact: S: 15.54 ± 1.81 US: 17.56 ± 1.88 Peak: S: 17.16 ± 1.62 US: 18.1 ± 1.75	At impact: S: 14.66 ± 1.43 US: 15.22 ± 1.8 Peak: S: 15. ± 1.4 US: 15.22 ± 1.7		
Gonzalez-Jurado et al. (2012)	Peak: 12.36 ± 1.75 At impact: 11.86 ± 1.93	Peak: 11.18 ± 0.76 At impact: 11.37 ± 0.89	Peak: 6.56 ± 1.02 At impact: 3.94 ± 1.07	Peak: 6.37 ± 0.45 At impact: 4.31 ± 0.88	Peak: 3.05 ± 0.32 At impact: 0.94 ± .33	Peak: 3.00 ± 0.31 At impact: 1.27 ± 0.31			Peak: 16.34 ± 2.05 At impact: 16.34 ± 2.05	Peak: 14.52 ± 1.15 At impact: 14.52 ± 1.15
Sakamoto et al. (2013)									19.9 ± 1.2	17.4 ± 1.0
Katis et al. (2015)	Peak: A: 13.41 ± 1.65 P: 12.28 ± 2.28	Peak: 12.77 ± 1.21	Peak: A: 7.95 ± 0.69 P: 7.00 ± 0.89	Peak: 7.29 ± 0.74	Peak: A: 3.00 ± 0.41 P: 2.45 ± 0.58	Peak: 2.63 ± 0.43				
Sakamoto et al. (2016)									Mean: 21.2 ± 6.8	Mean: 17.8 ± 1.4
Smith and Gilleard (2016)									Pre-impact: 16.37 ± 1.04	Pre-impact: 15.77 ± 0.37
Navandar et al. (2016)	Peak: DL: 18.32 ± 0.95 NDL: 17.16 ± 1.26	Peak: DL: 16.12 ± 1.37 NDL: 14.88 ± 1.33					Peak: DL: 22.68 ± 1.11 NDL: 20.95 ± 1.43	Peak: DL: 19.58 ± 1.86 NDL: 17.76 ± 2.17		

Navandar et al. (2017) Navandar et al. (2018)	Peak: UI: DL: 18.38 ± 1.02 NDL: 17.11 ± 1.28 I: DL: 18 ± 0 NDL: 18 ± 0	Peak: UI: DL: 16.25 ± 1.48 NDL: 14.76 ± 1.37 I: DL: 15.67 ± 0.82 NDL: 14.76 ± 1.37	Peak: DL: I: 9.67 ± 0.58 UI: 10.13 ±0.62 NDL: I: 10.00 ± 0 UI: 9.22 ± 0.81	Peak: DL: I: 8.67 ± 0.82 UI: 9.05 ± 0.83 NDL: I: 8.50 ± 0.58 UI: 8.33 ± 1.06	Peak: DL: I: 4.33 ± 1.15 UI: 4.38 ± 0.62 NDL: I: 4.00 ± 0 UI: 4.22 ± 0.65	Peak: DL: I: 3.50 ± 0.84 UI: 4.1 ± 0.45 NDL: I: 4.00 ± 0 UI: 3.81.0 ± 0.6	Peak: UI: DL: 22.81 ± 1.11 NDL: 20.83 ± 1.38 I: DL: 22.0 ± 1.00 NDL: 23.0 ± 0.00	Peak: UI: DL: 19.7 ± 2.03 NDL: 17.71 ± 2.31 I: DL: 19.17 ± 1.17 NDL: 18.00 ± 1.41			

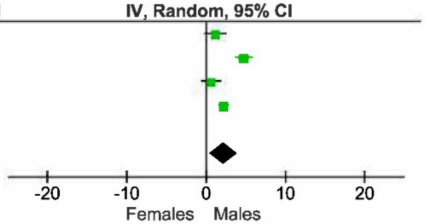
APPENDIX 8: Systematic Review Forest Plots of Pre-Sensitivity Meta-Analysis Results

A. Mean ball velocity (pre-sensitivity analysis)

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Gheidi and Sadeghi (2010)	12.36	1.75	7	11.18	0.76	7	23.5%	1.18 [-0.23, 2.59]
Gonzalez-Jurado et al. (2012)	16.62	1.9	11	11.86	0.032	11	25.1%	4.76 [3.64, 5.88]
Katis et al. (2015)	13.41	1.65	10	12.77	1.21	10	24.3%	0.64 [-0.63, 1.91]
Navandar et al. 1 (2016)	18.32	0.95	19	16.12	1.37	26	27.1%	2.20 [1.52, 2.88]
Total (95% CI)			**47**			**54**	**100.0%**	**2.22 [0.59, 3.85]**

Heterogeneity: $Tau^2 = 2.43$; $Chi^2 = 27.49$, df = 3 ($P < 0.00001$); $I^2 = 89\%$
Test for overall effect: Z = 2.67 (P = 0.008)

Mean Difference IV, Random, 95% CI

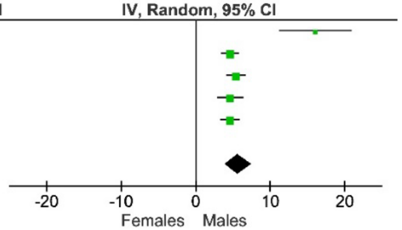


B. Peak ankle linear velocity (pre-sensitivity analysis)

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Chanda and Mondal (2018)	42.82	7.28	10	26.78	3.03	10	8.3%	16.04 [11.15, 20.93]
Sakamoto et al. (2010)	26.6	1.6	17	22	2	17	23.9%	4.60 [3.38, 5.82]
Sakamoto et al. (2016)	27.9	1.3	6	22.5	1	6	23.4%	5.40 [4.09, 6.71]
Sakamoto et al. 1, 2, 3 (2011, 2012, 2013)	26.6	2.6	17	22	2.6	17	21.1%	4.60 [2.85, 6.35]
Sakamoto et al. A, B (2013, 2014)	26.6	2	13	22	1.4	13	23.3%	4.60 [3.27, 5.93]
Total (95% CI)			**63**			**63**	**100.0%**	**5.73 [4.05, 7.41]**

Heterogeneity: $Tau^2 = 2.69$; $Chi^2 = 20.92$, df = 4 ($P = 0.0003$); $I^2 = 81\%$
Test for overall effect: Z = 6.68 ($P < 0.00001$)

Mean Difference IV, Random, 95% CI

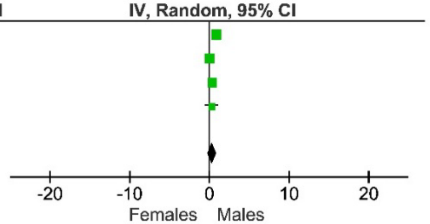


C. Peak hip linear velocity (pre-sensitivity analysis)

Study or Subgroup	Males Mean	Males SD	Males Total	Females Mean	Females SD	Females Total	Weight	Mean Difference IV, Random, 95% CI
Gheidi and Sadeghi (2010)	3.71	0.09	7	2.84	0.08	7	29.6%	0.87 [0.78, 0.96]
Gonzalez-Jurado et al. (2012)	3.05	0.32	11	3	0.31	11	27.7%	0.05 [-0.21, 0.31]
Katis et al. (2015)	3	0.41	10	2.63	0.43	10	25.9%	0.37 [0.00, 0.74]
Navandar et al. 3 (2018)	4.38	0.62	19	4.1	2.03	26	16.8%	0.28 [-0.55, 1.11]
Total (95% CI)			**47**			**54**	**100.0%**	**0.41 [-0.10, 0.93]**

Heterogeneity: $Tau^2 = 0.23$; $Chi^2 = 39.37$, df = 3 ($P < 0.00001$); $I^2 = 92\%$
Test for overall effect: Z = 1.58 (P = 0.11)

Mean Difference IV, Random, 95% CI



APPENDIX 9: Systematic Review Joint Range of Motion Results Tables

Kicking Leg Range of Motion Results Table.

Author	Hip (°)		Knee (°)		Ankle (°)	
	Males	Females	Males	Females	Males	Females
Gheidi and Sadeghi (2010)	At impact: S: 146.86 ± 11.400 US: 146.96 ± 9.500	At impact: S: 163.35 ± 10.20 US: 165.06 ± 11.60	At impact: S: 147.50 ± 10.800 US: 149.91 ± 11.60	At impact: S: 129.36 ± 8.300 US: 137.17 ± 9.100	At impact: S: 114.34 ± 4.1 US: 128.91 ± 8.6	At impact: S: 109.36 ± 4.3 US: 124.01 ± 6.2
Sakamoto et al. (2012)	Mean before impact: Instep: 72.3 ± 9.4 Inside: 52.5 ± 8.6	Mean before impact: Instep: 60.4 ± 5.3 Inside: 46.5 ± 7.6	Mean before impact: Instep: 175.5 ± 7.9 Inside: 157.4 ± 4.6	Mean before impact: Instep: 166.9 ± 5.5 Inside: 155.8 ± 8.2		
Smith and Gilleard (2016)	Peak ext: -24.7 ± 6.8 Abd at impact: 15.7 ± 7.4	Peak ext: -32.1 ± 1.7 Abd at impact: 25.5 ± 7.0			At impact: -28.8 ± 6.4	At impact: -20.5 ± 5.6
Navandar et al. (2016)	Peak ext: DL: -12.42 ± 7.76 NDL: -9.05 ± 8.99 At impact: DL: 27.16 ± 8.53 NDL: 30.58 ± 9.52	Peak ext: DL: -14.73 ± 9.37 NDL: -11.96 ± 9.30 At impact: DL: 27.35 ± 10.08 NDL: 29.64 ± 9.38	Peak: DL: 118.11 ± 8.31 NDL: 115.95 ± 8.58 At impact: DL: 42.95 ± 9.84 NDL: 47.47 ± 14.49	Peak: DL: 111.96 ± 11.55 NDL: 113.68 ± 11.27 At impact: DL: 45.12 ± 8.95 NDL: 56.68 ± 12.55		
Navandar et al. (2017)			UI: DL: 118 ± 8 NDL: 116 ± 9 I: DL: 118 ± 9 NDL: 122 ± 0	UI: DL: 112 ± 11 NDL: 114 ± 12 I: DL: 113 ± 13 NDL: 110 ± 8		

Navandar et al. (2018)	Backswing phase: DL: I: -12 ± 4 UI: -13 ± 8 NDL: I: -1 ± 0 UI: -10 ± 9 Leg cocking phase: DL: I: 11 ± 4 UI: 15 ± 6 NDL: I: 21 ± UI: 16 ± 9 Leg acceleration phase: DL: I: 23 ± 4 UI: 28 ± 9 NDL: I: 37 ± 0 UI: 30 ± 10 Follow-through phase: DL: I: 90 ± 13 UI: 97 ± 16 NDL: I: 110 ± 0 UI: 93 ± 15	Backswing phase: DL: I: -14 ± 11 UI: -15 ± 9 NDL: I: -8 ± 7 UI: -13 ± 10 Leg cocking phase: DL: I: 14 ± 10 UI: 12 ± 10 NDL: I: 13 ± 5 UI: 14 ± 9 Leg acceleration phase: DL: I: 30 ± 8 UI: 27 ± 11 NDL: I: 30 ± 10 UI: 30 ± 9 Follow-through phase: DL: I: 89 ± 12 UI: 86 ± 17 NDL: I: 83 ± 15 UI: 83 ± 18	Backswing phase: DL: I: 79 ± 10 UI: 79 ± 10 NDL: I: 75 ± 0 UI: 72 ± 8 Leg cocking phase: DL: I: 118 ± 9 UI: 118 ± 9 NDL: I: 122 ± 0 UI: 116 ± 9 Leg acceleration phase DL: I: 44 ± 5 UI: 43 ± 11 NDL: I: 66 ± 0 UI: 46 ± 14 Follow-through phase DL: I: 36 ± 19 UI: 27 ± 20 NDL: I: 29 ± 0 UI: 28 ± 16	Backswing phase: DL: I: 73 ± 6 UI: 67 ± 19 NDL: I: 58 ± 10 UI: 72 ± 14 Leg cocking phase: DL: I: 113 ± 13 UI: 112 ± 11 NDL: I: 110 ± 8 UI: 114 ± 12 Leg acceleration phase: DL: I: 45 ± 9 UI: 45 ± 9 NDL: I: 51 ± 15 UI: 58 ± 12 Follow-through phase: DL: I: 31 ± 14 UI: 26 ± 12 NDL: I: 27 ± 14 UI: 26 ± 14		
Chanda and Mondal (2018)	GC: 236.72 ± 5.65 BC: 301.9 ± 5.5 FT: 350.8 ± 30.38	GC: 236.78 ± 11.48 BC: 306.88 ± 3.67 FT: 367.42 ± 47.47	GC: 83.80 ± 4.97 BC: 140.60 ± 11.01 FT: 153.40 ± 38.04	GC: 86.40 ± 14.54 BC: 138.0 ± 6.96 FT: 174.0 ± 9.67	GC: 127.6 ± 9.91 BC: 121.40 ± 12.01 FT: 120.00 ± 16.94	GC: 131.00 ± 8.83 BC: 141.20 ± 9.98 FT: 113.80 ± 32.04

Trunk Range of Motion Results Table

Author	Trunk flexion (°)		Trunk side flexion (°)		Trunk rotation (°)	
	Males	Females	Males	Females	Males	Females
Orloff et al. (2008)	Foot plant: -11 ± 3 Ball contact: 3 ± 8	Foot plant: -10 ± 7 Ball contact: 13 ± 10	Ball contact: -3 ± 11	Ball contact: 8 ± 9		
Shan (2009)	NP: 8.9 ± 1.7 SP: 6.6 ± 1.2	NP: 8.0 ± 2.0 SP: 46.3 ± 5.4			NP: 9.2 ± 1.3 SP: 20.8 ± 3.4	NP: 8.7 ± 2.6 SP: 23.8 ± 3.4

APPENDIX 10: Systematic Review Joint Angular Velocity Results Table

Author	Knee (rad/s)		Hip (rad/s)		Ankle (rad/s)	
	Males	Females	Males	Females	Males	Females
Barfield et al. (2002)	At impact: DL: 19.4 ± 1.9 NDL: 16.4 ± 1.4	At impact: DL: 19.8 ± 4.5 NDL: 16.1 ± 4.0				
Katis et al. (2015)	Peak: A: 1698.4 ± 236.2 P: 1325.5 ± 279.7	Peak: 1386.4 ± 255.7	Peak: A: 817.4 ± 121.7 P: 742.5 ± 145.9	Peak: 758.6 ± 93.4	Peak: A: 1720 ± 224.5 P: 1328.4 ± 341.7	Peak: 1520.4 ± 209.8
Navandar et al. (2016)	Peak: DL: 17.84 ± 4.15 NDL: 17.37 ± 3.39 At impact: DL: -32.00 ± 4.08 NDL: -28.26 ± 4.98	Peak: DL: 15.85 ± 2.59 NDL: 15.72 ± 2.09 At impact: DL: -27.69 ± 4.47 NDL: -25.96 ± 3.84	Peak: DL: 14.32 ± 2.26 NDL: 12.53 ± 2.25 At impact: DL: -1.05 ± 3.01 NDL: 0.37 ± 2.89	Peak: DL: 14.27 ± 2.31 NDL: 12.80 ± 2.35 At impact: DL: -2.31 ± 3.03 NDL: -1.88 ± 1.98		
Navandar et al. (2017)	UI: DL: 18 ± 4 NDL: 17 ± 3 I: DL: 17 ± 3 NDL: 21 ± 0	UI: DL: 16 ± 3 NDL: 15 ± 2 I: DL: 15 ± 2 NDL: 17 ± 1	UI: DL: 18 ± 4 NDL: 17 ± -3 I: DL: 17 ± 3 NDL: 21 ± 0	UI: DL: 16 ± 3 NDL: 15 ± 2 I: DL: 15 ± 2 NDL: 17 ± 1		
Navandar et al. (2018)	Backswing phase: DL: I: 16 ± 2 UI: 17 ± 5 NDL: I: 20 ± 0 UI: 16 ± 2 Leg cocking phase: DL: I: 0 ± 1	Backswing phase: DL: I: 14 ± 3 UI: 15 ± 3 NDL: I: 17 ± 1 UI: 14 ± 3 Leg cocking phase: DL: I: 0 ± 1	Backswing phase: DL: I: 0 ± 0 UI: 0 ± 0 NDL: I: 0 ± 0 UI: 0 ± 0 Leg cocking phase: DL: I: 11 ± 1	Backswing phase: DL: I: 0 ± 0 UI: 0 ± 0 NDL: I: 0 ± 0 UI: 0 ± 0 Leg cocking phase: DL: I: 11 ± 2		

	UI: 0 ± 1 NDL: I: 0 ± 0 UI: 0 ± 1 Leg acceleration phase: DL: I: -32 ± 3 UI: -32 ± 4 NDL: I: -31 ± 0 UI: -28 ± 5 Follow through phase: DL: I: 9 ± 1 UI: 5 ± 3 NDL: I: 0 ± 0 UI: 4 ± 5	UI: 0 ± 1 NDL: I: 0 ± 1 UI: 0 ± 1 Leg acceleration phase: DL: I: -26 ± 4 UI: -28 ± 5 NDL: I: -25 ± 3 UI: -26 ± 4 Follow-through phase: DL: I: 1 ± 4 UI: 4 ± 5 NDL: I: 2 ± 4 UI: 4 ± 4	UI: 11 ± 1 NDL: I: 10 ± 0 UI: 10 ± 2 Leg acceleration phase: DL: I: -1 ± 2 UI: -1 ± 3 NDL: I: 0 ± 0 UI: 0 ± 3 Follow through phase: DL: I: 4 ± 1 UI: 3 ± 2 NDL: I: -1 ± 0 UI: 2 ± 3	UI: 12 ± 2 NDL: I: 8 ± 0 UI: 10 ± 2 Leg acceleration phase: DL: I: -1 ± 2 UI: -3 ± 3 NDL: I: -1 ± 1 UI: -2 ± 2 Follow-through phase: DL: I: -1 ± 2 UI: 1 ± 2 NDL: I: 1 ± 3 UI: 2 ± 3		
Chanda and Mondal (2018)	At impact: 1314.67 ± 187.73	At impact: 430.0 ± 135.99	At impact: 606.5 ± 48.58	At impact: 584 ± 68.57	At impact: 77.0 ± 90.5	At impact: 108.33 ± 115.62

APPENDIX 11: Systematic Review Joint Angular Displacement Results Table

Author	Ankle		Knee		Hip					
					Flx/ext		Abd/add		Rotation	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Sakamoto and Asai (2013)	DF/PF: Instep: 11.9 ± 8.3° Inside: 4.9 ± 2.1° IR/ER: Instep: 5.4 ± 2.4° Inside: 14.9 ± 6.7° In/eversion Instep: 4.8 ± 3.2 Inside: 5.2 ± 3.3	DF/PF: Instep: 14.3 ± 8.6° Inside: 5.2 ± 2.3° IR/ER: Instep: 7.3 ± 3.0° Inside: 16.1 ± 6.8° In/eversion: Instep: 3.6 ± 1.3° Inside: 4.8 ± 2.0°								
Smith and Gilleard (2016)	Toe-off: -39.0 ± 5.5° Heel strike: -35.0 ± 11.5° Min PF: -19.0 ± 9.0° Pre-impact: -29.0 ± 6.5°	Toe-off: -37.0 ± 7.0° Heel strike: -22.0 ± 10.5° Min PF: 0.5 ± 19.0° Pre-impact: -18.0 ± 7.5°	Toe-off: 16.5 ± 7.5° Heel strike: 68.5 ± 12.0° Max flx: 92.5 ± 8.0° Pre-impact: 53.5 ± 13.5°	Toe-off: 6.5 ± 6.0° Heel strike: 77.5 ± 15.0° Max flx: 97.0 ± 12.0° Pre-impact: 46.5 ± 14.0°	Toe-off: -15.5 ± 8.0° Max ext: -24.5 ± 7.0° Heel strike: -20.0 ± 11.5° Impact: 0.0 ± 12.0°	Toe-off: -18.5 ± 3.0° Max ext: -34.5 ± 2.0° Heel strike: -28.0 ± 5.0° Impact: 7.5 ± 8.0°	Max abd: 22.5 ± 7.5°	Max abd: 24.0 ± 5.0°	Max ER: -9.5 ± 8.5° Max IR: 8.5 ± 11.0° Pre-impact: 4.5 ± 11.5°	Max ER: -7.5 ± 6.5° Max IR: 14.5 ± 4.0° Pre-impact: 6.0 ± 8.5°
Chanda and Mondal (2018)	GC to BC: 8.20 ± 8.98°/s	GC to BC: 13.00 ± 13.87°/s	GC to BC: 56.80 ± 13.14°/s	GC to BC: 51.60 ± 6.32°/s	GC to BC: 65.18 ± 8.23°/s	GC to BC: 70.08 ± 4.55°/s				

APPENDIX 12: Systematic Review Joint Torque and Moment Results Tables

Joint Torques Results Table

Author	Knee (Nm)						Hip (Nm)					
	Flx		Abd		IR/ER		Flx		Abd		IR/ER	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Sakamoto et al. (2013)	60.6 ± 2.6	41.0 ± 2.6	25.6 ± 2.6	16.0 ± 1.8								
Sakamoto et al. (2016)	Instep: 83.1 ± 18.1 Side-foot: 66.8 ± 17.3	Instep: 62.8 ± 28.2 Side-foot: 56.4 ± 21.9	Instep: 38.6 ± 10.8 Side-foot: 35.3 ± 10.7	Instep: 28.4 ± 8.1 Side-foot: 28.6 ± 7.2	Instep: 3.4 ± 3.4 Side-foot: 2.8 ± 2.9	Instep: 3.2 ± 1.5 Side-foot: 3.2 ± 0.9	Instep: 250 ± 29.7 Side-foot: 229.3 ± 44.1	Instep: 196.5 ± 32.2 Side-foot: 184.8 ± 31.4	Instep: 109.5 ± 10.0 Side-foot: 102.1 ± 10.9	Instep: 76.8 ± 20.5 Side-foot: 75.1 ± 17.3	Instep: -13.8 ± 10.5 Side-foot: -7.2 ± 18.8	Instep: -10.9 ± 6.8 Side-foot: -9.3 ± 6.4

Joint Moment Results Table

Author	Hip (Nm/kg)				Knee (Nm/kg)			
	Flx		Ext		Flx		Ext	
	Males	Females	Males	Female	Males	Females	Males	Females
Navandar et al. (2017) Navandar et al. (2018)	DL: I: 4 ± 0 UI: 4.13 ± 0.72 NDL: I: 4 ± 0 UI: 3.44 ± 0.86	DL: I: 4.67 ± 1.37 UI: 3.95 ± 0.76 NDL: I: 3.75 ± 0.5 UI: 3.76 ± 1.14	DL: I: -3.33 ± 0.58 UI: -3.88 ± 0.72 NDL: I: 4 ± 0 UI: -3.28 ± 0.89	DL: I: -4 ± 1.41 UI: -3.55 ± 1.05 NDL: I: -2.5 ± 0.58 UI: -2.67 ± 1.24	DL: I: 2 ± 0 UI: 1.94 ± 0.25 NDL: I: 2 ± 0 UI: 1.67 ± 0.49	DL: I: 1.83 ± 0.75 UI: 1.7 ± 0.57 NDL: I: 1.25 ± 0.5 UI: 1.57 ± 0.6	DL: I: -1.33 ± 0.58 UI: -1.19 ± 0.4 NDL: I: -1 ± 0 UI: -1.17 ± 0.38	DL: I: -1.33 ± 0.52 UI: -1.1 ± 0.31 NDL: I: -1 ± 0 UI: -1 ± 0.32

APPENDIX 13: Systematic Review Tension Arc Results Table

Author	SL shoulder ROM (°)		Hip flx/ext ROM (°)		Knee flx/ext ROM (°)		Trunk flx/ext ROM (°)		Trunk rotation ROM (°)	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Shan (2009)	NP: 54.3 ± 5.7 SP: 157.8 ± 2.3	NP: 46.7 ± 6.9 SP: 113.7 ± 0.2	NP: 72.4 ± 6.9 SP: 130.4 ± 10.2	NP: 72.0 ± 6.1 SP: 92.4 ± 8.8	NP: 80.2 ± 9.7 SP: 107.9 ± 7.8	NP: 125.6 ± 11.8 SP: 113 ± 10.4	NP: 8.99 ± 1.7 SP: 6.69 ± 1.2	NP: 8.09 ± 2.0 SP: 46.39 ± 5.4	NP: 9.29 ± 1.3 SP: 20.89 ± 3.4	NP: 8.79 ± 2.6 SP: 23.89 ± 3.6
Shan et al. (2012)	NP: 129.2 ± 11.4 SP: 161.4 ± 15.9	NP: 45.6 ± 9.2 SP: 116.7 ± 1.3	NP: 76.7 ± 7.2 SP: 129.2 ± 11.4	NP: 69.1 ± 6 SP: 91.2 ± 7.8	NP: 85 ± 7.9 SP: 110.9 ± 8.3	NP: 122.0 ± 14.5 SP: 117.5 ± 8.9	NP: 8.4 ± 1.3 SP: 22.5 ± 4.7	NP: 9.6 ± 2.5 SP: 45.6 ± 7.3	NP: 8.4 ± 1.3 SP: 22.5 ± 4.7	NP: 22.5 ± 4.7 SP: 25.6 ± 4.8

APPENDIX 14: Systematic Review Ball-to-Foot Force Results Table

Author	Coefficient of restitution		Ball-to-foot velocity ratio	
	Males	Females	Males	Females
Sakamoto et al. (2010)	Instep: 0.59 ± 0.12 In-front: 0.57 ± 0.12 Inside: 0.77 ± 0.10	Instep: 0.57 ± 0.10 In-front: 0.57 ± 0.12 Inside: 0.64 ± 0.15		
Sakamoto et al. (2011) Sakamoto et al. (2012) Sakamoto et al. (2013)			Instep: Mean: 1.31 ± 0.18 Near COG: ~1.45 Inside: Mean: 1.41 ± 0.16 Near COG: ~1.15	Instep: Mean: 1.23 ± 0.16 Near COG: ~1.35 Inside: Mean: 1.37 ± 0.14 Near COG: ~1.14

APPENDIX 15: Risk Assessment Screening Tool

Risk Assessment – Health Research

Research Study Title: An investigation of kicking biomechanics and hip and groin health in male and female rugby players.		
School / Department: School of Medicine/Discipline of Physiotherapy		
Principle Investigator: Dr Fiona Wilson (supervisor) Molly Boyne (Research MSc Student)	*[22/12/20]*	*Reviewed/Consulted*
Supervisor: Dr Fiona Wilson	*[22/12/20]*	*Reviewed/Consulted*
Trinity College DPO or DDPO (Research)	*01. 02. 2021*	*Reviewed/*Consulted
DPIA required for this study?	Yes/No	
Rationale (no DPIA needed): This study will investigate the hip and groin health and kicking biomechanics of male and female rugby players. It will involve a hip and groin health screening (subjective report, range of motion and strength) and a kicking assessment (kicking biomechanics and accuracy). This research does not involve any vulnerable or high-risk populations. Participants are high-performing male and female rugby athletes who routinely perform kicking duties for their club at a competitive level. Minimal risk is posed to them by partaking in this study. The included assessments indicate low risk to the rights and freedoms of individuals involved. The research is not associated with any clinical site. **DPO/DDPO opinion: No DPIA required. This is low volume (40 participants) and low risk from a privacy perspective – data will be coded, and no envisaged sharing with third parties. Data subject rights are clear in PIL.**		
Signed by PI ______________________	**Date:** 23/03/2021	

Introduction

Under the Health Research Regulations 2018 an assessment of the data protection implications of proposed health research must be carried out. Where the assessment indicates a high risk to the rights and freedoms of individuals a **Data Protection Impact Assessment** ("**DPIA**") must then be carried out.

It is important to note that a DPIA is required as standard for research studies conducted at St. James's Hospital, Tallaght University Hospital and all clinical sites in which Trinity researchers are active. The REPC approved Trinity College DPIA (Health Research) Template must be used by Trinity researchers.

This template is available to download at:

https://www.tcd.ie/info_compliance/data-protection/dpias/

Further information on DPIAs is available from the Data Protection Commission at:

https://www.dataprotection.ie/sites/default/files/uploads/2019-10/Guide%20to%20Data%20Protection%20Impact%20Assessments%20%28DPIAs%29_Oct19.pdf

Further information on the Health Research Regulations ("**HRR**") is available from the Health Research Board at:

https://www.hrb.ie/funding/gdpr-guidance-for-researchers/health-research-regulations-2018/health-research-regulations-2018-faq/

Further information on data protection compliance at Trinity College is available at:

https://www.tcd.ie/info_compliance/data-protection/

Definitions used throughout this document are outlined in Appendix 1.

If you are uncertain of data protection compliance requirements please contact the College Data Protection Office at dataprotection@tcd.ie.

Instruction

Please complete this document and send it to the Trinity College Data Protection Office for review.

Each screening question in this assessment questionnaire **must** be answered. You should add any additional, relevant question(s) dependant on the risk and / or processing operation(s) you are assessing. These screening questions will help to identify if a DPIA is required and provide valuable insight into processing risk areas.

The list of screening questions in this document do not remove the general requirement to carry out proper and effective risk assessment and risk management of proposed data processing operations nor does the list exempt Trinity College from the obligation to ensure compliance with data protection legislation. The fact that a type of processing is absent from this list does not mean that such processing can be carried out without a DPIA.

Study Details

Number of study participants.	~40 participants (20 male and 20 female high-performing rugby players competing in the Energia Community Series). Additional participants will be recruited from the IRFU Ireland Sevens Men's and Women's Teams.
Provide a systematic description of the processing operations, including the scope, duration and purposes of the processing. Describe any software that is used for the research data collection.	Personal data (participants' names and contact details) will be collected from emails of interest from athletes to the research team. Players will be assigned an individual code for pseudonymising purposes. Personal data will be stored in a password protected file on an encrypted PC in the Physiotherapy Postgraduate Office in the Trinity Centre for Health Sciences and accessible only to handlers, Dr Fiona Wilson and Molly Boyne. Hard copy consent and demographic information forms will be kept in a locked cabinet in this room. Identification code keys will be maintained and stored by Molly Boyne on a password-protected file on her encrypted laptop. Upon completion of the Masters studies, these code keys will be shared with Dr Wilson, as supervisor. Sensitive information will be collected as part of the research testing process. This includes: - Demographic information such as rugby, kicking and previous injury history - Hip and groin assessment data, such as the Copenhagen Hip and Groin Outcome Score questionnaire, hip range of motion, and hip and hamstring strength, - Kicking leg biomechanical data collected from electrogoniometers attached to the hip, knee and ankle of the participant - Video footage of kicking assessment taken using three GoPro cameras This data will pseudonymised and stored securely in password-protected files on encrypted laptops. Only Dr Fiona Wilson, Dr Nicol van Dyk and Molly Boyne will have access to demographic and hip and groin data. The identification code keys for this data will be shared with Dr Wilson following the conclusion of Masters project. Electrogoniometer data will be processed by the research team using Biometric Ltd software installed on

	the secured PC in the Physiotherapy Postgraduate Office and on the encrypted laptops of Dr Ciaran Simms and Ross Norman. Video footage of kicks will be processed quantitatively by the engineering colleagues in the research team. OpenPose Motion Capture software will be applied to these videos for the purpose of establishing 3D joint biomechanics during kicks. The footage will be reviewed qualitatively by the physiotherapy and rugby contingent of the research team. This data will be processed securely and transferred via password-protected email files, due to travel restrictions during the current global health crisis. The results of each player's assessments and feedback on their performance will be shared with them, if they are willing to be contacted by the researchers following their testing session. In the case of the Ireland Sevens players, they will also be asked to consent to their hip and groin health assessment and kicking analysis data being shared with medical and coaching staff within the IRFU Sevens Programme, for the purpose of performance analysis and injury prevention.
Details of parties involved (internal stakeholders, collaborators, external organisations (public/private, third parties) etc. (add rows if necessary). Specify the data controller, data processor and joint controller(s).	**Data Controller:** Trinity College Dublin **Data Handlers :** Dr Fiona Wilson and Molly Boyne **Internal stakeholders:** *Research team* Ms Molly Boyne, Discipline of Physiotherapy, Trinity College Dublin. Dr Fiona Wilson, Discipline of Physiotherapy, Trinity College Dublin. Dr Ciaran Simms, Department of Mechanical and Manufacturing Engineering, Trinity College Dublin. Mr Ross Norman, Department of Mechanical and Manufacturing Engineering, Trinity College Dublin. Dr Nicol van Dyk, Irish Rugby Football Union. Mr Emmet Farrell, Leinster Rugby. Mr Garreth Farrell, Leinster Rugby. **External organisations:** *Clubs competing in the Men's and Women's Energia Community Series* Women's ECS Leinster Conference Teams: - Railway Union RFC - Old Belvedere RFC - Blackrock College RFC

	- Suttonians RFC - Wicklow RFC Men's ECS Leinster Conference 1 Teams: - Lansdowne RFC - UCD RFC - Terenure College RFC - Dublin University RFC - Clontarf RFC - Naas RFC - Old Belvedere RFC - Old Wesley RFC - St. Mary's College RFC *IRFU Ireland Sevens Programme players and management.*
Provide information as to why the use of personal data is necessary for the study.	Participating athletes' names will be collected to allow for the initial identification of each participant and assignment of individual codes for pseudonymization of data. Their contact details will be stored for the purpose of liaising with potential and confirmed candidates, test scheduling, provision of feedback and gaining consent for the future use of data. Consent forms will be obtained for processing this data. Some personal data will be obtained from participants with consent in the form of a demographic questionnaire. General information (sex, age, height, weight) is being collected on this form. These details affect a player's kicking performance and will be used by the research team to compare the sexes in this study. Rugby history, including affiliated club, current and previous competitive levels, will be documented. This location information is personal data and is necessary for the research team to know how past experience has influenced players' kicking ability. Participants will be asked to complete a Covid-19 symptom declaration form prior to attending their testing session. This data is being collected to ensure the safety of themselves, the research team, and other participants.

Screening Question	Yes	No	N/A	Detail
Does the study involve a large number of participants? Note that the number of data subjects concerned should be considered either as a specific number or as a proportion of the relevant population. In addition, the following should be considered: 1. the volume of data and/or the range of different data items being processed; 2. the duration, or permanence, of the data processing activity; and 3. the geographical extent of the processing activity.		✓		
Does the research involve processing of special categories of personal data which is identifiable or coded? See Appendix 1 for definition of 'special categories of personal data'.		✓		
Will the research involve participants who could be considered as vulnerable? See Appendix 1 for definition of 'vulnerable'.		✓		
Will the project involve the collection of new information about individuals?	✓			This study is investigating the hip and groin health and kicking biomechanics of male and female rugby players. Women's rugby is hugely under-researched, and data collected during this study will be the first of its kind in this population.
Screening Question	Yes	No	N/A	Detail

Is the information about individuals sensitive and therefore likely to raise privacy concerns or expectations? Example: Health records, criminal records or other information people would consider particularly private?		✓		
Will the project compel individuals to provide information about themselves?		✓		Participants will be asked to complete a demographic questionnaire regarding their playing, kicking and injury history. They will also be asked to complete a Covid-19 symptom declaration form prior to testing. They will be fully informed of the details of these questionnaires and may give or remove consent for this data to be collected as they choose.
Will information about individuals be disclosed to organisations or people who have not previously had routine access to the information? **If so, is there a contract or other document to govern this arrangement?**		✓		
Will the processing of individuals' data be for a new or unrelated purpose?		✓		
Does the processing involve the use of new technology or systems or organisational solutions which might be perceived as being intrusive? Example: Combining use of fingerprint and face recognition for improved physical access control, using a video analysis system to single out cars and recognise licence plates), or certain		✓		OpenPose Motion Capture Software will be used in this research as part of the kicking assessment. This is a 3D markerless motion analysis system designed to examine human movement and motor performance. It is not intrusive and will not be used for any purpose other than to analyse kicking biomechanics in participating athletes and compare it to the data collected using Electrogoniometers.

"Internet of Things" applications or certain innovative software solutions.				
Screening Question	**Yes**	**No**	**N/A**	**Detail**
Could the processing result in decisions being made or actions being taking against individual(s), in ways that could have a significant impact on them? Example: the processing may lead to the exclusion or discrimination against individuals. Example: An online tool used to award a loan or a recruitment aptitude test that uses pre-programmed algorithms and criteria.		✓		
Will the project require you to contact individuals in ways which they may find intrusive?		✓		Potential participants will be contacted through a gatekeeper in their club or through support staff in the IRFU Sevens Programme . They will not receive formal communication from the research team without expressing interest in partaking in this study. They can request to leave the study or cease communication at any time.
Will any of the processing activities make it difficult for the data subject(s) to exercise their rights under GDPR (right to access, right to information et.)?		✓		

Does the processing require systematic and/or extensive evaluation, or scoring (via automated means or otherwise – including profiling and predicting) of personal aspects of individuals especially concerning a data subject's performance at work, economic situation, health, personal preferences, reliability or behaviour, location or movements? Example: Offering genetic tests in order to assess or predict disease/health risks or gathering social media profile data for generating profiles for contact directories or marketing.		✓		
Screening Question	**Yes**	**No**	**N/A**	**Detail**
Are you transferring data to entities located outside of the EU?		✓		
Will the processing combine, link or cross-reference (compare or match) separate datasets from multiple sources in a way which could exceed the reasonable expectations of the data subject and/or where such linking significantly contributes to or is used for profiling or behavioural analysis of individuals? Example: Two or more data processing operations performed for different purposes and/or by different data controllers being combined.		✓		
Are you sharing the data with a commercial entity?		✓		

Does the processing involve systematic monitoring of a publicly accessible area on a large scale? (E.g. CCTV)		✓		

APPENDIX 16: Protocol 1 Faculty of Health Sciences Ethical Approval

Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin
Ollscoil Átha Cliath | The University of Dublin

Molly Boyne,
Department of Physiotherapy,
Trinity Centre for Health
Sciences,St James's Hospital,
Dublin 8

16th January 2020

Ref: 191208

Title of Study: Kicking kinematics and hip and groin health in male and female rugby

players.Dear Molly,

Further to a meeting of the Faculty of Health Sciences Ethics Committee held in December. We arepleased to inform you that the above project has ethical approval to proceed.

This study has been ethically approved. We would advise you to seek review and comments on your DPIAfrom the DPO if required prior to study commencement'

As a researcher you must ensure that you comply with other relevant regulations, including DATAPROTECTION and HEALTH AND SAFETY.

Yours sincerely,

pp [signature]

Prof. Jacintha
O'Sullivan
Chairperson
Faculty Research Ethics Committee

Dámh na nEolaíochtaí Sláinte
Foirgneamh na Ceimice,
Coláiste na Tríonóide,
Ollscoil Átha Cliath,
Baile Átha Cliath 2, Éire.

Faculty of Health Sciences
Chemistry Building,
Trinity College Dublin,
The University of Dublin,
Dublin 2, Ireland.

www.healthsciences.tcd.ie

APPENDIX 17: Protocol 1 IRFU Sports Medicine Committee Approval

IRFU

IRFU Research Committee

6th March 2020

Ms Molly Boyne,
Postgraduate Research Masters Student,
Trinity College
Dublin

Dear Ms Boyle

RE: 01-20

Many thanks for your responses to the reviewers comments relating to your application to the IRFU Research Committee.

Having reviewed your responses and received a copy of the ethics approval the project has now received full approval and can proceed.

Best of luck with the study.

Kind regards,

Yours sincerely

Dr Giles Warrington PhD, FACSM

Chair

APPENDIX 18: Protocol 1 Email to Gatekeepers

Dear club person (to be addressed specifically to each club),

I am a postgraduate student undertaking my Masters by Research in Physiotherapy in Trinity College Dublin. I am also a player with Railway Union Rugby Club. I am contacting you with regards to my research project, entitled, "Kicking kinematics and hip and groin health in male and female rugby players." This study will involve assessing the hip and groin health of male and female rugby kickers, and examining their kicking technique using motion capture technology. The aim of this research is to investigate the biomechanics of how female players kick compared to men, and how this is associated with injury, with the goal of providing coaches and players with insights on how to improve their technique and performance and reduce the risk of injuries.

Ethical approval to conduct this study has been received from Trinity College Dublin's Faculty of Health Science Research Ethics Committee. A requirement of this ethical approval is that we do not contact players directly but that the recruitment email for the study is sent out by a gatekeeper. The role of the gatekeeper is to act as a liaison between the research team and potential participants in the study. In doing so, they will send two emails to players: the first, an initial recruitment email, and the second, a reminder email one week later. Would you, in your capacity as a club representative, be willing to act as a gatekeeper for this study?

The initial email in question is at the bottom of this email and the information leaflet for the study is attached. I ask that you forward this email and information leaflet to all female members of your club.

If you are happy to take on the role of gatekeeper, please respond to this email confirming so. Should you have any questions or wish to discuss this further, please do not hesitate to contact me via email or on 0862363608.

Kind Regards,

Molly Boyne

MSc Physiotherapy Student

Trinity College Dublin

APPENDIX 19: Protocol 1 Email to Potential Participants

Dear all,

I am currently investigating the kicking kinematics and hip and groin health of male and female rugby players.

To do this, I am recruiting athletes from teams competing in the highest competitive domestic leagues in Ireland.

You are eligible to participate in this research if you are:

- Over 18 years of age
- Competing in the Women's All Ireland League or Women's Leinster League Division 1, or Men's AIL Division 1A or 1B
- Performed kicking duties in at least two competitive fixtures in the 2017/18 and/or 2018/19 seasons

The study will involve one testing session per participant in the Sport Ireland Campus in Blanchardstown. This session will consist of two components, a hip and groin examination and a kicking assessment, and will last 60-80 minutes. Full details of the study can be found in the information leaflet attached to this email.

If you are eligible and interested in participating in this study, or have any additional questions, please contact the researcher at boynem@tcd.ie. Your participation would be valued and appreciated, but you are under no obligation to participate.

With many thanks in anticipation of your participation.

Yours faithfully,

Molly Boyne

MSc Physiotherapy Student

Trinity College Dublin

APPENDIX 20: Hip and Groin Outcome Score Questionnaire

HAGOS: Hip and Groin Outcome Score

Questionnaire concerning hip and/or groin problems

Today's date: _____/______/______ Date of birth: _____/______/________

Name: ____

INSTRUCTIONS: This questionnaire asks for your view about your hip and/or groin problem. The questions should be answered considering your hip and/or groin function during the **past week**. This information will help us keep track of how you feel, and how well you are able to do your usual activities.

Answer **every** question by ticking the appropriate box. Tick only one box for each question. If a question does not pertain to you or you have not experienced it in the past week please make your "best guess" as to which response would be the most accurate.

Symptoms

These questions should be answered considering your hip and/or groin **symptoms** and difficulties during the **past week**.

S1 Do you feel discomfort in your hip and/or groin?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2 Do you hear clicking or any other type of noise from your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

S3 Do you have difficulties stretching your legs far out to the side?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S4 Do you have difficulties taking full strides when you walk?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S5 Do you experience sudden twinging/stabbing sensations in your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Stiffness

The following questions concern the amount of stiffness you have experienced during the **past week** in your hip and/or groin. Stiffness is a sensation of restriction or slowness in the ease with which you move your hip and/or groin.

S6 How severe is your hip and/or groin stiffness after first awakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7 How severe is your hip and/or groin stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

P1 How often is your hip and/or groin painful?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

P2 How often do you have pain in areas other than your hip and/or groin that you think may be related to your hip and/or groin problem?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

The following questions concern the amount of pain you have experienced during the **past week** in your hip and/or groin. **What amount of hip and/or groin pain have you experienced during the following activities?**

P3 Straightening your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4 Bending your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5 Walking up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6 At night while in bed (pain that disturbs your sleep)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7 Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

The following questions concern the amount of pain you have experienced during the **past week** in your hip and/or groin. **What amount of hip and/or groin pain have you experienced during the following activities?**

P8 Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9 Walking on a hard surface (asphalt, concrete, etc.)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P10 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Physical function, daily living

The following questions concern your physical function. **For each of the following activities please indicate the degree of difficulty you have experienced in the past week due to your hip and/or groin problem.**

A1 Walking up stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2 Bending down, e.g. to pick something up from the floor

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A3 Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4 Lying in bed (turning over or maintaining the same hip position for a long time)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5 Heavy domestic duties (scrubbing floors, vacuuming, moving heavy boxes etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when participating in higher-level activities. Answer **every** question by ticking the appropriate box. If a question does not pertain to you or you have not experienced it in the past week, please make your "best guess" as to which response would be the most accurate. **The questions should be answered considering what degree of difficulty you have experienced during the following activities in the past week due to problems with your hip and/or groin.**

SP1 Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2 Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3 Twisting/pivoting on a weight bearing leg

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5 Running as fast as you can

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP6 Bringing the leg forcefully forward and/or out to the side, such as in kicking, skating etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP7 Sudden explosive movements that involve quick footwork, such as accelerations, decelerations, change of directions etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP8 Situations where the leg is stretched into an outer position (such as when the leg is placed as far away from the body as possible)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	

Participation in physical activities

The following questions are about your ability to participate in your preferred physical activities. Physical activities include sporting activities as well as all other forms of activity where you become slightly out of breath. **When you answer these questions consider to what degree your ability to participate in physical activities during the past week has been affected by your hip and/or groin problem.**

PA1 Are you able to participate in your preferred physical activities for as long as you would like?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

PA2 Are you able to participate in your preferred physical activities at your normal performance level?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

Quality of Life

Q1 How often are you aware of your hip and/or groin problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2 Have you modified your lifestyle to avoid activities potentially damaging to your hip and/or groin?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3 In general, how much difficulty do you have with your hip and/or groin?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Q4 Does your hip and/or groin problem affect your mood in a negative way?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Q5 Do you feel restricted due to your hip and/or groin problem?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Thank you very much for completing all the questions in this questionnaire

APPENDIX 21: Hip and Groin Testing Procedure

Range of motion testing

For practical purposes, testing will be conducted in the following order:

1. Hip flexion (Figure 1)
2. Hip abduction/adduction (0°) (Figure 2/3)
3. Hip internal/external rotation (Figure 4)
4. Hip extension (Figure 6)
5. Bent Knee Fall Out (Figure 7)

Hip Flexion

Starting position: Supine on plinth with hip and knees at neutral 0°. Arms resting by sides.

Axis location: On femoral greater trochanter.

Stationary arm: Parallel to the trunk

Movement arm: Parallel with the longitudinal axis of the femur in line with the lateral femoral condyle.

Stabilise: Stabilise pelvis to prevent rotation or posterior tilt.

Test procedure: Start with both legs extended and pelvis in neutral. To perform test, flex hip maximally while keeping low back on plinth and non-test leg extended.

Figure 1. Hip flexion range of motion assessment. Source: http://at.uwa.edu/gon/hip.htm

Hip Abduction

Starting position: Supine on plinth with hip and knees at neutral 0°. Arms resting by sides.

Axis location: On ASIS of testing leg.

Stationary arm: Making a straight line across the pelvis between ASISs

Movement arm: Along the midline of the femur pointing to the centre of the patella.

Stabilise: Stabilise pelvis to prevent rotation or posterior tilt.

Test procedure: Body positioned to the edge of one side of the plinth. Start with both legs extended and pelvis in neutral. To perform test, abduct hip maximally while keeping non-test leg on the plinth.

Figure 2. Hip abduction range of motion assessment. Source: http://at.uwa.edu/gon/hip.htm

Hip Adduction

Starting position: Supine on plinth with hip and knees at neutral 0°. Arms resting by sides.

Axis location: On ASIS of testing leg.

Stationary arm: Making a straight line across the pelvis between ASISs

Movement arm: Along the midline of the femur pointing to the centre of the patella.

Stabilise: Stabilise pelvis to prevent rotation or posterior tilt.

Test procedure: Start with non-testing leg abducted to keep space for adducting limb. Keep both legs extended and pelvis in neutral. To perform test, adduct hip maximally while keeping non-test leg on the plinth.

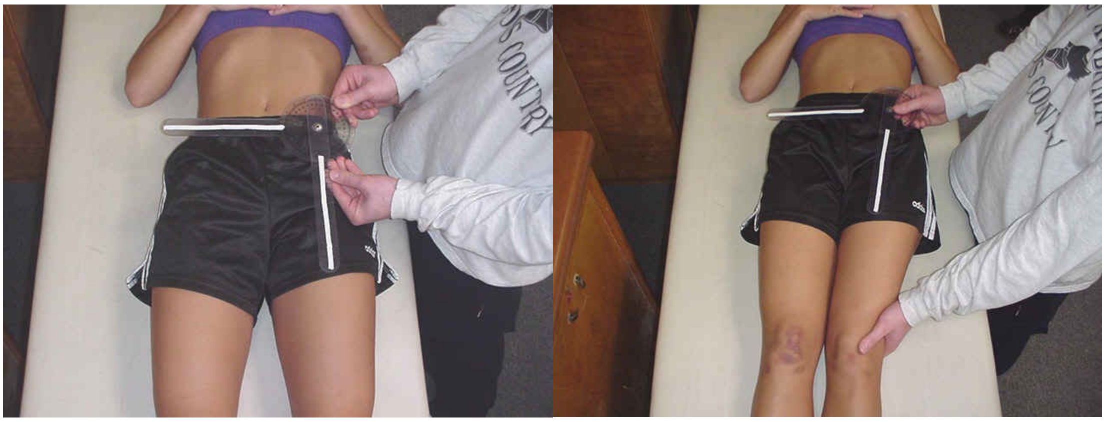


Figure 3. Hip adduction range of motion assessment. Source: http://at.uwa.edu/gon/hip.htm

Hip Internal Rotation

Starting position: Supine on plinth with one hip and knee flexed to 90°. Other leg extended. Hands resting by side.

Axis location: Over patella apex.

Stationary arm: Parallel to the line across the ASISs of the pelvis.

Movement arm: Along the tibia.

Stabilise: Support lower leg and stabilise knee to prevent abduction.

Test procedure: Start with non-testing leg extended. Testing hip and knee flexed to 90°, with the knee and lower leg stabilised. To perform test, internally hip maximally while avoiding abduction and keeping non-test leg extended.

Hip External Rotation

Starting position: Supine on plinth with one hip and knee flexed to 90°. Other leg extended. Hands resting by side.

Axis location: Over patella apex.

Stationary arm: Parallel to the line across the ASISs of the pelvis.

Movement arm: Along the tibia.

Stabilise: Support lower leg and stabilise knee to prevent abduction.

Test procedure: Start with non-testing leg extended. Testing hip and knee flexed to 90°, with the knee and lower leg stabilised. To perform test, internally hip maximally while avoiding abduction and keeping non-test leg extended.

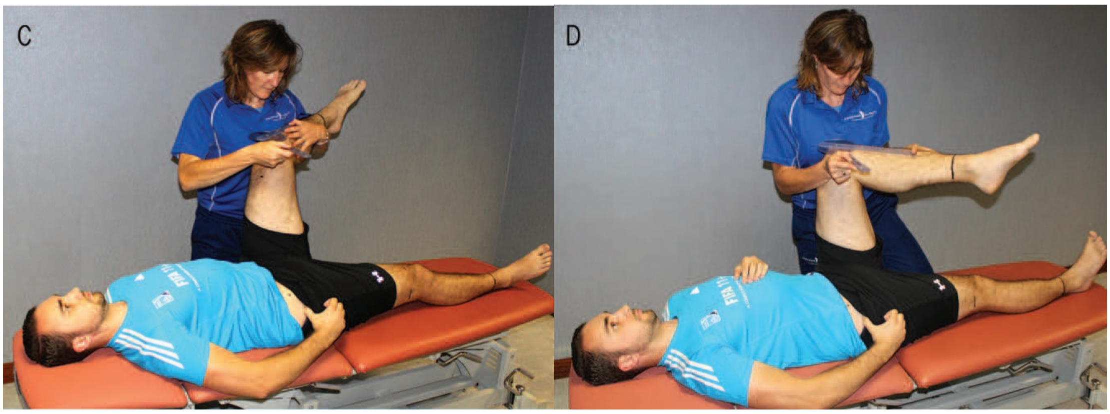


Figure 4. Hip internal/external rotation range of motion assessment Source: (Mosler et al., 2018)

Hip Extension

Starting position: Prone on plinth with hip and knees at neutral 0°. Hands under forehead.

Axis location: On femoral greater trochanter.

Stationary arm: Parallel to the trunk

Movement arm: Parallel with the longitudinal axis of the femur in line with the lateral femoral condyle.

Stabilise: Stabilise pelvis to prevent rotation or anterior tilt.

Test procedure: Start with both legs extended and pelvis in neutral. To perform test, extend hip maximally while keeping ASISs on plinth and non-test leg extended.

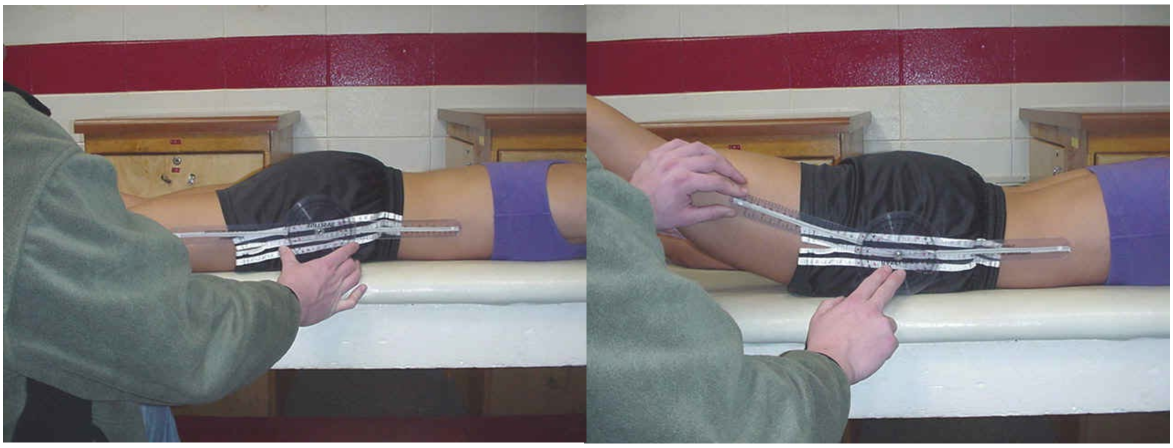


Figure 6. Hip extension range of motion assessment. Source: http://at.uwa.edu/gon/hip.htm

Bent Knee Fall Out Test

Starting position: Crook lying on plinth with hips flexed to 45° and knees flexed to 90°, as verified by goniometer. Hands resting by side and feet together.

Test procedure: Start with hips flexed to 45°, knees flexed to 90° and hips together. To perform test, instruct the participant to let both knees fall outward while keeping their feet together. Use gentle overpressure to ensure they have reached the limit of their movement.

Figure 7. Bent knee fall out test.

Source: Mosler et al. (2018)

Measurement: Measure the distance between the most distal point on the head of the fibula and the surface of the plinth using a tape measure to the nearest 0.5cm.

Strength assessments

Hip Strength Assessment

For practical purposes, muscle testing will be conducted in the following order:

1. Hip flexion (Figure 8)
2. Hip extension (Figure 9)
3. Hip internal rotation (Figure 10)
4. Hip external rotation (Figure 11)
5. Hip abduction/adduction (45°) (Figure 12/13)
6. Hip abduction/adduction (0°) (Figure 14/15)

Hip Flexion

Body position: Seated on a foam gym box in an upright position. Hands holding side of box.

Hip position: Testing leg in 90° flexion with foot not touching floor. Opposite leg extended.

Knee position: Testing leg in 90° flexion. Opposite leg extended. Knees hip width apart.

Sensor position: Top of the knee (immediately above proximal pole of the patella). Set outer sensor to flat paddle position. Position the cross bar as low as possible while not in contact with the knee.

Test procedure: Start with foot slightly off the floor and the top of the knee directly below the outer sensor. To perform test, flex hip to achieve contact with sensor.

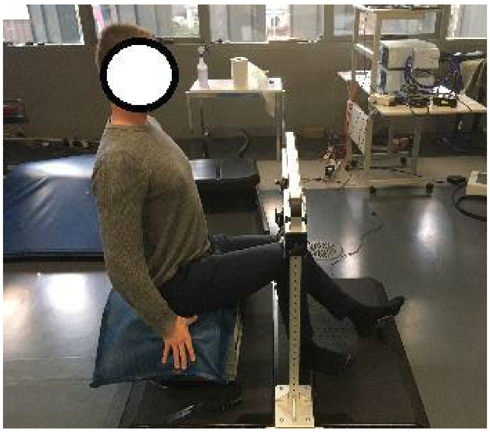


Figure 8. Hip flexion strength assessment.

Source: Thomas and Opar (2018)

Hip Extension

Body position: Prone lying with testing leg inside in frame and the non-testing leg outside – frame between legs. Hands under forehead.

Hip position: Neutral 0°.

Knee position: Testing leg between 0 and 15°. Non-testing leg extended.

Sensor position: 5cm proximal to the knee crease. Set outer sensor to flat paddle position. Position the cross bar as low as possible while not in contact with the thigh.

Test procedure: Start with front of thigh in contact with the floor below the outer sensor. To perform test, extend hip to achieve contact with sensor.

Figure 9. Hip extension strength assessment.

Source: Thomas and Opar (2018)

Hip Internal Rotation

Body position: Prone lying with hands under forehead.

Hip position: Neutral 0°.

Knee position: Both knees flexed to 90°.

Sensor position: Sensors returned to vertical position. Lateral malleoli in contact with outer sensors.

Test procedure: Start with lateral malleoli in contact with the outer sensor. To perform test, internally rotate hip to push lateral ankles into sensor.

Figure 10. Hip IR strength assessment.

Source: Thomas and Opar (2018)

Hip External Rotation

Body position: Prone lying with hands under forehead.

Hip position: Neutral 0°.

Knee position: Both knees flexed to 90°.

Sensor position: Sensors returned to vertical position. Medial malleoli in contact with inner sensors.

Test procedure: Start with medial malleoli in contact with the inner sensor. To perform test, externally rotate hip to squeeze medial ankles into sensors.

Figure 11. Hip ER strength assessment.

Source: Thomas and Opar (2018)

Hip Adduction (45°)

Body position: Supine lying with arms by side.

Hip position: Hips flexed to 45° as measured with a goniometer on the first trial.

Knee position: Knees flexed to approx. 90°.

Sensor position: Sensors in vertical position. Medial femoral condyles in contact with inner sensors.

Test procedure: Start with medial femoral condyles in contact with the inner sensor. To perform test, adduct hips to squeeze medial knees together against the sensor.

Figure 12. Hip adduction (45°) strength assessment.

Source: Thomas and Opar (2018)

Hip Abduction (45°)

Body position: Supine lying with arms by side.

Hip position: Hips flexed to 45° as measured with a goniometer on the first trial.

Knee position: Knees flexed to approx. 90°.

Sensor position: Sensors in vertical position. Lateral femoral condyles in contact with outer sensors.

Test procedure: Start with lateral femoral condyles in contact with the outer sensors. To perform test, abduct hips to push lateral knees against the sensors.

Figure 13. Hip abduction (45°) strength assessment.

Source: Thomas and Opar (2018)

Hip Adduction (0°)

Body position: Supine lying with arms by side.

Hip position: Neutral 0°.

Knee position: Neutral 0°.

Sensor position: Sensors in vertical position with frame as low to the ground as possible. Medial malleoli in contact with inner sensors.

Test procedure: Start with medial malleoli in contact with the inner sensor. To perform test, adduct hips to squeeze medial ankles together against the sensor.

Figure 14. Hip adduction (0°) strength assessment.

Source: Thomas and Opar (2018)

Hip Abduction (0°)

Body position: Supine lying with arms by side.

Hip position: Neutral 0°.

Knee position: Neutral 0°.

Sensor position: Sensors in vertical position with frame as low to the ground as possible. Lateral malleoli in contact with outer sensors.

Test procedure: Start with lateral malleoli in contact with the outer sensors. To perform test, abduct hips to push lateral ankles out against the sensors.

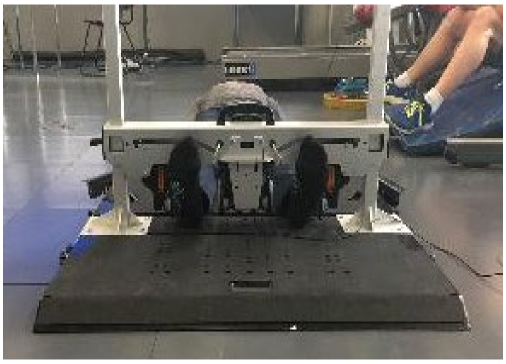


Figure 15. Hip adduction (45°) strength assessment.

Source: Thomas and Opar (2018)

Hamstring strength assessment

Nordic Hamstring Exercises

Body position: Kneeling on the NordBord with hands across chest.

Hip position: Neutral 0°.

Knee position: Flexed to 90°, kneeling on the padded platform.

Sensor position: NordBord ankle hooks are linked to force sensors. Hooks should be slid over feet onto ankles and positioned 1cm above level of malleoli.

Figure 16. Hamstring strength assessment.

Source: Vald Performance

Test procedure: Start with participant kneeling comfortably on the pad and ankle secured in the hooks. To perform test, eccentrically extend knees using hamstrings to slowly lower body towards the ground, keeping trunk and hips in neutral.

APPENDIX 22: Participant Information Leaflet

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

PARTICIPANT INFORMATION LEAFLET

STUDY TITLE: An investigation of kicking biomechanics in female rugby players.

Site	Trinity Centre for Health Sciences, St. James's Hospital. IRFU High Performance Centre, Sport Ireland Campus.
Lead Investigator **Co-Investigator(s)** **Research Supervisor**	Ms Molly Boyne, Research Masters Student, Discipline of Physiotherapy, Trinity College Dublin: boynem@tcd.ie Dr Ciaran Simms, Associate Professor, Department of Mechanical and Manufacturing Engineering, Trinity College Dublin: csimms@tcd.ie Dr Nicol van Dyk, IRFU Injury Surveillance and Medical Research Officer, Irish Rugby Football Union: nicol.vandyk@irfu.ie Garreth Farrell, Head Physiotherapist, Leinster Rugby: garreth.farrell@leinsterrugby.ie Emmet Farrell, Head Analyst and Kicking Coach, Leinster Rugby: emmet.farrell@leinsterrugby.ie Mr Ross Norman, Bioengineering Masters Student, Department of Mechanical and Manufacturing Engineering, Trinity College Dublin: normanr@tcd.ie Dr Fiona Wilson, Associate Professor, Discipline of Physiotherapy, Trinity College Dublin: wilsonf@tcd.ie
Data Controllers	Trinity College Dublin
Data Protection Officer	Data Protection Officer, Secretary's Office, Trinity College Dublin, Dublin 2

Introduction

You are being invited to take part in a research study that is being carried at Trinity College Dublin by Molly Boyne. She is a Research Masters Student in the Discipline of Physiotherapy and a rugby player with Railway Union RFC.

Before you decide whether or not you wish to take part in this study, please read this information sheet carefully. This is a Participant Information Leaflet, designed to explain the research to you as clearly and concisely as possible. If you have any questions, please do not hesitate to contact the Lead Investigator, Molly Boyne. Don't feel rushed or under pressure to make a quick decision. You should understand the risks and benefits of taking part in this study so that you can make a decision that is right for you. You may wish to discuss it with your family, friends, coaches, or GP.

This leaflet has five main parts:

Part 1 – The Study

Part 2 – Data Protection

Part 3 – Costs, Funding and Approval

Part 4 – Future Research

Part 5 – Further Information

Part 1 – The Study

Why is this study being done?

Women's rugby is one of the fastest growing sports in the world, with over 2.7 million players worldwide. This represents a 28% increase since 2017, following a successful Women's Rugby World Cup in Ireland. Despite this development, there is a huge lack of research into the game, both in terms of performance and injury data. This has led to a variety of misconceptions and negative ideas about women's rugby. One such preconception was highlighted by journalist Kate Rowan, in an article in the Telegraph, entitled, "Why lack of early practice explains women rugby players' kicking struggles." Here, she discussed the traditional view of women's rugby as being a freer flowing, running style game, with less tactical kicking and kicks to score compared the men's game. The general consensus is that this is because women's kicking ability lags behind that of their male counterparts. This opinion is supported by statistical evidence from the Women's Rugby World Cup 2017, where female kickers had a success rate of 53%, compared to 75% kicking accuracy by male kickers at the Rugby World Cup in 2015. However, there has been no research conducted, examining kicking in women's rugby and investigating the factors which may be contributing to poor performance. Research in women's soccer has highlighted the physical differences, such as strength and flexibility, as well as differences in muscle use and leg position, in female kickers, compared to men, but it remains unclear to what extent this applies in rugby. These gaps in the literature need to be filled to allow the women's game to develop, and to ensure improvements in performance indicators and injury prevention.

Aim of current study

By carrying out this study, we are aiming to investigate kicking biomechanics in female and male rugby players, to establish key characteristics of this skill in the sexes and how they compare to each other.

Why have I been invited to take part?

You have been invited to participate in this study because you are an elite rugby player, actively training with the Ireland National 7s or 15s Programme. The researchers will also be testing high performing kickers competing in the Energia Community Series Leinster Conferences.

Is there any reason I can't participate in this study?

You cannot take part in this research study if any of the following apply to you:

- Players under 18 years old
- Players with a recent or long-term ongoing injury
- Players who are not actively training with the Ireland 7s or 15s Programme
- Exclusion for any other reason deemed appropriate by the Lead Investigator

How will the study be carried out?

To participate, you will be asked to meet with the research team in the IRFU High Performance Centre on one occasion. A testing session will be conducted with you lasting approximately 60 mins. You will be asked to follow Covid-19 precautions throughout this process, including completing a symptom questionnaire, sanitising your hands, wearing personal protective equipment, and maintaining social distancing where possible.

Upon arrival, you will be greeted by researchers in a reception area at the entrance to the High Performance Centre. You will be instructed in appropriate Covid-19 protocols and directed to the testing zone. The testing process and equipment will be explained to you, and you will have the opportunity to clarify any queries. You will be asked to complete a demographic questionnaire to collect information, such as your gender, age, injury history, rugby competitive level, kicking experience, and coaching history. You will also be asked to fill in a Covid-19 declaration form and comply with all associated precautions, including practicing hand hygiene and wearing personal protective equipment. Please bring your own kicking tee and active wear, including shorts and rugby boots, with you to wear during testing.

Kicking assessment

Testing will be carried out on the indoor 4G pitch in the High Performance Centre. You will be asked to wear suitable active wear and rugby boots for this assessment. You will be instructed to perform a 15-minute standardised including 5 minutes of self-directed, non-recorded kicking practice. Following the warm-up, this kicking assessment will be explained to you and the testing equipment set up.

This equipment consists of three Electrogoniometers (Figure 1 and 2) that will be attached at your kicking leg hip, knee, and ankle joints. These are sensors that record the range of motion of your joints. They are connected to a recording device using a series of wires. The recording device will be held in a pouch around your waist (Figure 3). The sensors will be attached to your leg using double-sided body tape and secured using elastic adhesive bandages. If you have any allergy to adhesive tapes, you are advised to inform the research team before this stage of the testing is commenced. To ensure a secure fixation of the devices, body hair may need to be shaved.

Figure 1

Figure 2

Figure 3

The content of your kicking assessment will vary depending on whether you play 7s, 15s, or both. If you play 7s, you will be asked to perform accurate drop kicks towards the goal posts from three locations along the 22m line of the pitch: in line with the left goal post, in the centre of the goal posts, and in line with the right goal post. If you are a 15s player or are confident as a 7s player, you will also be asked to perform maximal effort, accurate place kicks towards the goal posts from three locations along the 22m line of the pitch: 15m to the left of the posts, between the posts and 15m to the right of the posts respectively. You will kick from your own tee or one will be provided for you. You will be asked to perform three accurate kicks from each location.

Are there any benefits to taking part in this research?

Participating in this study will not result in monetary gain or benefit in kind. However, as an experienced, high-performing athlete, the testing carried out in this study may benefit you in a performance capacity. The kicking data collected from the study will be analysed by mechanical engineers with experience in rugby biomechanics, sports physiotherapists, and the Leinster Senior kicking coach. They will thoroughly examine your technique and kinematics, and will provide feedback, where desired, that may improve your kicking performance. Data will also be provided to management of your squad with your permission, which may be useful to apply to your training in terms of skill development.

Are there any risks to me or others if I take part? What will happen if something goes wrong?

The risks associated with participating in this study are anticipated to be minimal. You will be asked to declare any injuries or niggles before the kicking assessment to ensure that you do not have any underlying issues which could be exacerbated by your participation in the study. There is a minor risk that you may become injured when kicking during the test, however, a comprehensive warm-up and cool-down will be encouraged to prevent such an event. In the unlikely case of any injury, the Lead Investigator is a qualified physiotherapist, trained to manage such situations.

There is a small risk that a connection to your identity could be made, however, great care will be taken at all times to ensure the confidentiality of your information. The risk to participants of a breach of confidentiality is considered very low.

All possible precautions will be taken throughout the entire testing process to protect you and the research team from Covid-19. All researchers involved in hands-on testing with you have been vaccinated. All participants will have a negative PCR test and be screened for symptoms before being admitted to the testing site. Personal protective equipment will be worn by everyone in the testing venue. Social distancing will be maintained where possible and a thorough cleaning protocol has been established. Despite these precautions, there is a very small risk of contracting Covid-19 while participating in this research. In the unlikely scenario that you develop symptoms following your testing session, you are asked to contact the research team and your GP.

Should any other adverse event occur during the study, the researchers carrying out this study are covered by standard medical malpractice insurance.

Do I have to take part? Can I withdraw from the study?

Participation in this study is **fully voluntary**. Once you have read this document and have had the study procedures, risks, and benefits explained, you will be asked to sign a consent form before the testing begins**. You do not have to take part** in this study and should not feel obliged to do so.

You may withdraw participation at any time without giving a reason, even if the study has already begun. If you choose not to take part anymore, you will be asked to fill in a withdrawal form. If you wish, you can ask for your data collected to date to be destroyed. If you request this, we will destroy all data that is still in our possession. We will no longer use or share your data for research from this point onwards. However, it will not be possible to destroy data already used in research studies prior to this time.

If you do not give consent, or withdraw your consent, no further attempt will be made to access your data. If you wish to opt-out at any stage, contact the research team (details below). In turn, the research team may stop your participation in the study at any time without your consent.

What should I expect on the day of testing, if I consent to take part in this study?

If you consent to taking part, the following points summarise how to prepare for testing:

- Please meet researchers in the reception area at the entrance to the High Performance Centre's indoor pitch at the time you have been scheduled.
- You will be asked to adhere to Covid-19 precautions throughout the testing process, including sanitising your hands, wearing personal protective equipment, and maintaining social distancing where possible.
- You will be asked to review this information leaflet and sign a consent form if you agree to take part.
- You will then be asked to fill out a questionnaire about your playing, kicking, and injury history, to give the researchers some background on your experiences when analysing your results.
- You will take part in a kicking assessment on the indoor pitch. You will be asked to take place kicks and/or drop kicks towards the goal posts from three locations on the pitch. These kicks will be recorded using devices placed at your hip, knee, and ankle to measure the movement at these joints.
- Please wear active wear and bring shorts with you if possible.
- Please bring both comfortable shoes that you can exercise in and rugby boots for the two portions of the test.
- If you have a kicking tee that you use competitively, please bring it, or a tee/cone will be provided for you.

Part 2 – Data Protection

What information about me (personal data) will be used as part of this study?

Personal data to be collected in this study will include your gender, age, injury history, rugby competitive level, kicking experience and coaching history. This information will give the research team some background to you as a player and will be used to make sense of the results of your kicking tests. We are collecting the minimum amount of personal data that is relevant to the purpose of the study to provide context to our study findings and allow comparison between groups.

What will happen to my personal data? Will it be kept confidential?

If you sign the consent form, your personal data, including contact details, will be kept in written form, securely locked in a filing cabinet in the Postgraduate Physiotherapy Office in the Trinity Centre for Health Sciences. This is only accessible by the Lead Investigator and the Research Supervisor. All other data we collect from you during the study will be coded with a number ID to maintain your confidentiality. The key to this code will be kept securely in a password protected file on an encrypted laptop belonging to the Lead Investigator, separate from all other data we have collected. Only data required to achieve the aims of this study will be collected. This data is being collected and analysed to gain insight into the kicking biomechanics of female rugby players, as compared to males, and no damage or distress will come to you as a result of processing this data.

Your name and personal details will never be published or disclosed to anyone outside the research team. All information relating to you in hard-copy form will be stored in a locked filing cabinet in a secure office accessible only by the research team. Information and records in electronic form will be stored on a password-protected files on secure, encrypted laptops accessible only to members of the research team. Your study information and results will be retained for 7 years, in keeping will good research practice standards and data protection legislation. It will be destroyed after this time (electronic data will be erased, and hard copy forms will be shredded).

Who will access and use my personal data as part of this study?

Only the Lead Investigator and Research Supervisor on the research team will have access to your personal data. Your personal data will not be shared with anyone outside of the research team at Trinity College Dublin unless you give consent for the results of your assessments to be shared with the medical and coaching staff in your associated national programme. If you are happy for this data to be shared, you will be asked to confirm this with your initials on the consent form. The data controller (the organisation responsible for keeping your information safe) for this study is Trinity College Dublin. The Lead Investigator and Research Supervisor have undergone training in data protection law and practice, prior to starting this research. The researchers in this project are bound by our Professional Code of Conduct to maintain confidentiality regarding all data gained during this research. The data processors for this study are the Lead Investigator, Molly Boyne, and the Research Supervisor, Dr Fiona Wilson.

How will my data be used during the current research study?

Your data will be used for health research, which is in the public interest. The information collected in this study will be analysed, and the overall findings of this study may be published in international peer reviewed journals and shared at research conferences. However, your data will remain coded throughout and your personal identifiers will never be published or disclosed to anyone outside of this research team, except for the Ireland national medical and coaching staff with your consent. The results of the study may be used with your consent for comparative purposes in other studies of a similar nature (Please see Part 4 – Future Research, below).

What is the lawful basis to use my personal data?

Your data will be processed under the lawful basis according to the following Articles of the EU General Data Protection Act 2016: Article 6(1)(e), where the processing is carried out in the public interest, and Article 9(2)(j), where processing is necessary for archiving in the public interest, scientific or historical research purposes, or statistical purposes.

What are my rights?

You have the right to:

- Access your personal data
- Rectify or correct any mistakes with your personal data
- Have your personal data erased or deleted. However, it will not be possible to remove anonymised data
- Data portability (move your personal data from one controller to another)
- Object to the use of your personal data (except if it has already been analysed, or anonymised)

You can exercise these rights by contacting any member of the research team, or the Trinity College Data Protection Officer (see contact details below). If you are not satisfied with how your data is being used, you can also lodge a complaint to the Data Protection Commissioner (Phone: +353 57 8684800 or +353 (0)761 104 800; website: www.dataprotection.ie ; address: Office of the Data Protection Commission, 21 Fitzwilliam Square South, Dublin 2).

Part 3 – Costs, Funding and Approval

Has this study been approved by a research ethics committee?

Yes, this study received ethical approval on xx/xx/xxxx from the Faculty of Health Sciences Research Ethics Committee, Trinity College Dublin (e-mail: ethicscommittee@tcd.ie).

Who is organising and funding this study? Will results be used commercially?

This research project is self-funded by the Discipline of Physiotherapy, Trinity College Dublin, as part of postgraduate Masters research. The results will not be used for commercial purposes. You will not receive payment or reimbursement for your participation in this research.

Part 4 – Future Research

Will my personal data be used in future studies?

In the future, your personal data may be used, with your consent, for comparative purposes in other studies of a similar nature examining kicking biomechanics in rugby athletes. However, your data will remain coded and personal identifiers will never be published or disclosed to anyone outside of the research team. Your data will only be used for comparative purposes in other studies that have received ethical approval from the Research Ethics Committee. Future research may be conducted by the Lead Investigator, Molly Boyne, or by other researchers in the Discipline of Physiotherapy in Trinity College Dublin. Inclusion of your data in future research is voluntary and you can withdraw your consent to future research at any time.

Will I be contacted in the future?

After completion of the study, you may be contacted again by the researchers in relation to your study results and to offer feedback on them, should you so desire.

Part 5 – Further Information

Who should I contact for information or complaints?

For more information or answers to your questions about the study, your participation, and your rights, please contact the research team:

Principal Investigator/Research Supervisor:

Dr Fiona Wilson,

Associate Professor,

Discipline of Physiotherapy,

Trinity College Dublin

Contact: Tel (01) 8963534, E-mail: wilsonf@tcd.ie

Lead Investigator:

Ms. Molly Boyne,

Research Masters Student,

Trinity College Dublin

Contact: Tel (01) 8963613, E-mail: boynem@tcd.ie

Data Controller: Trinity College Dublin

For information regarding your rights under data protection law, please contact:

Data Protection Officer, Trinity College Dublin:

Contact E-mail: dataprotection@tcd.ie

Website: www.tcd.ie/privacy

Address: Secretary's Office, Trinity College Dublin, College Green, Dublin 2.

APPENDIX 23: Participant Consent Form

PARTICIPANT CONSENT FORM

Study title: An investigation of kicking biomechanics in female rugby players.

Location: Trinity College Dublin, Dublin 2.

IRFU High Performance Centre, Sport Ireland Campus.

There are 3 sections in this form. Each section has a statement and asks you to initial if you agree. The end of this form is for the researchers to complete.

Please ask any questions you may have when reading each of the statements.

Thank you for participating.

Please Initial the box if you agree with the statement. Please feel free to ask questions if there is something you do not understand.

Section 1: General Information	Initial
I confirm I have read and understood the **Participant Information Leaflet** for the above study. The information has been fully explained to me and I have been able to ask questions, all of which have been answered to my satisfaction.	
I understand that this study **is entirely voluntary, and if I decide that I do not want to take part, I can stop taking part in this study at any time without giving a reason**.	
I understand that all of my personal data will be kept private and confidential and that my name will not be disclosed to anyone outside of the research team.	
I understand that I **will not be paid for taking part in this study**.	
I know how to contact the research team if I need to.	
I agree to take part in this research study having been fully informed of the **risks, and benefits** which are set out in full in the participant information leaflet with which I have been provided.	
I agree to adhere to all Covid-19 precautions and protocols set out by the research team, in keeping with government guidelines. This includes, but is not limited to, declaring any symptoms to the researchers prior to or after the testing, wearing appropriate personal protective equipment, practicing good hand hygiene, and maintaining social distancing where possible.	
I agree to being contacted by researchers by email/phone as part of this research study.	

Section 2: Data Processing and Data Protection	Initial
I understand that personal data about me will be protected in accordance with the General Data Protection Regulation.	
I understand that all my personal data will be made non-identifiable (pseudonymised) for this study titled "An investigation of kicking biomechanics female rugby players", and my personal identifiers will not be shared with anyone outside the research team without my consent.	
I agree to allow the results of my kicking biomechanics analysis to be shared with appropriate medical and coaching staff in my associated national squad programme.	
I understand that **I can stop taking part in this study** at any time without giving a reason, and that I can request at any time that my personal data will be deleted and not be used (except where the data has already been analysed/published, or has been anonymised).	
I understand that my personal data will be used for this research study, and non-identifiable data may be published in peer reviewed journals, in presentations, and may be disseminated at conferences.	
I understand that my data will be stored for a total of 7 years in compliance with legal and regulatory obligations.	

Section 3: Future Use of Personal Data	Initial
I give permission for my personal data to be stored for *possible future research* at Trinity College Dublin, *related* to the current study (studies examining kicking related outcomes in rugby players) ***without further consent*** being required from me, but only if the research is approved by a Research Ethics Committee.	
I understand that my personal data used for possible future research (as above) may be published in peer reviewed journals, in presentations and may be disseminated at conferences, but my data will remain confidential and none of my personal identifiers will be disclosed in these circumstances.	
I understand that I am free to withdraw my consent to the use of my personal data in future similar studies at any time and my personal data will not be used and will be destroyed (unless the data has been analysed/published, or anonymised)	
I understand that I will not be paid for any future use of my personal data in future research as described above	

Participant's Name (BLOCK CAPITALS):	Witness Name (BLOCK CAPITALS):
Participant's Signature:	**Witness Signature:**
Date:	**Date:**
Participant's Phone Number/E-mail:	

To be completed by the Lead Investigator or nominee.

I, the undersigned, have taken the time to fully explain to the above participant the nature and purpose of this study in a way that they could understand. I have explained the risks and possible benefits involved. I have invited them to ask questions on any aspect of the study that concerned them.

I have given a copy of the participant information leaflet and consent form to the participant with contacts of the study team.

Researcher's Name (BLOCK CAPITALS):	
Researcher's Title & Qualifications:	
Researcher's Signature:	
Date:	

2 copies to be made: 1 for patient and 1 for research team.

APPENDIX 24: Demographic Information Questionnaire

General

What is your gender?

☐ Male

☐ Female

☐ Other

If other, please specify: __________________________

What age are you?

_____________ years

What is your height?

_____________ cm/ft and inches

What is your current weight?

_____________ lbs/stones/kg

Rugby

What national team are you involved with? Please tick all that apply.

☐ Women's 7s

☐ Women's 15s

☐ Men's 7s

☐ Men's u20s

What club are you associated with?

____

What position(s) do you play? If more than one, please specify most common position.

____

How long have you been playing rugby?

____

Please give details of your rugby playing history e.g previous teams, route to rugby …

____

____

____

Have you played or do you currently play any sports outside of rugby?

____

Kicking

Which is your preferred kicking leg?

- ☐ Left
- ☐ Right
- ☐ Both

How long have you been kicking competitively for?

____

Are you your team’s first choice kicker/one of several top choice kickers?

____

Do you have competitive experience performing the following kicks ? Please tick all that apply.

- ☐ Place kicks
- ☐ Drop kicks
- ☐ Punt kicks
- ☐ Box kicks

Have you ever received specific coaching for kicking?

- ☐ Yes
- ☐ No

Please give details:

____

____

____

Injury history

Please give details of any previous injuries:

____

____

____

Please give details of any current injuries:

____

____

Are you physically fit and well to participate in this study?

☐ Yes

☐ No

Is there any other information you wish to disclose to or share with the research team before commencing this assessment?

____
____
____

Many thanks for completing this questionnaire

APPENDIX 25: Kicking Assessment Warm-up Procedure

An adapted version of the FIFA 11+ programme was used as the standardised warm-up for the kicking assessment (Figure 1). It takes roughly 20 minutes to complete and consists of:

1. Running exercises (8 minutes)
2. Strength, plyometrics and balance exercises (10 minutes)
3. Running exercises (2 minutes)

1. Running exercises

Running straight ahead

Participants will start on the first cone and jog to the end of the line of cones. When they reach the fifth cone, they should shuffle around it and then jog backwards back to the first cone. Repeat this for 2 sets.

Running hip out

Having finished sidhe participant will jog through the setup, stopping at each cone to lift their knee and rotate their hip outwards. They should alternate between left and right legs each time. When they reach the end, they should turn and repeat the same on the way back through the cones. Perform one set.

Running hip in

After running with their hip out, the participant will return to the first cone and jog through the setup, stopping at each cone to lift their knee and rotate their hip inwards. They should alternate between left and right legs each time. When they reach the end, they should turn and repeat the same on the way back through the cones. Perform one set.

Side-shuffles around cone

Upon returning to the first cone, the participants will run forwards to the first set of cones. They will shuffle 90 degrees to the middle cone and shuffle a circle around it. They will side-step back to the cone they started on and continue onto the next cone and do the same, alternating between a forward and backwards circle each time. When they hit the last cone, they should swap to the other cone and repeat the process on the other side on the way back.

Side shuffles with jump

Upon returning to the first cone, the participants will run forwards to the first set of cones. They will shuffle 90 degrees to the middle cone, stop, jump laterally up and over it, landing on both legs with knees bent. They will side-step to the cone on the opposite side and jog forward to the next cone. Repeat the process up through the cones. When they reach the end cones, they should turn and repeat this process, this time when they reach the middle cones, they should jump laterally from two legs and land on their outside leg, with their knee bent. started on and continue onto the next cone and do the same, alternating between a forward and backwards circle each time.

Running quickly backwards and forwards

Upon returning to the first cone, the participants will run quickly forwards to the second set of cones. They will then jog backwards quickly to the first set of cones and then run forward to the fourth set of cones. They will jog backwards to the third set of cones and run forward to the fifth set of cones. Participants will jog back to the first set of cones and repeat this again.

2. Strength, plyometrics and balance exercises

Plank with alternate legs

Participants will be asked to assume a plank position, supporting themselves on their forearms and feet. They will maintain this position for 30 seconds, lifting each leg in turn and holding it for 2 seconds. Repeat this 2 times.

Side plank with raising and lowering hip

Participants will be asked to assume a side plank position, supporting themselves on their forearm and feet. They will maintain this position for 30 seconds, lowering their hip to the ground and back up. Repeat 2 times each side.

Hamstring curls

Participants will be asked to kneel on a foam pad. The tester will hold their ankles. The participant will cross their hands across their chest and perform a Nordic curl, using their hamstrings to ensure a slow, controlled descent. Complete 6 reps.

Single leg stance ball throw

Participants will be asked to stand on one leg with their stance knee slightly bent. The tester will stand 2-3m away from them and throw a rugby ball back and forth with them. Hold for 30 seconds and swap legs. Repeat 2 times each leg.

Walking lunges

Participants will be asked to put their hands on their hips and lunge forward until their hips and knees are flexed to 90 degrees. They should continue this up the length of the cones until they have done 10 each side. This should be repeated twice.

Lateral jumps

Participants will be asked to perform lateral jumps. They will stand on one leg with their upper body leaning slightly forward from the waist and their hips and knees slightly bent. They should jump 1m sideways from the standing leg to the free leg and land gently on the ball of their foot. They should hold the landing for 3 seconds and repeat the exercise for 30 seconds. They can move forward as they do it if they like. They should complete 2 sets.

3. Running

Running across the pitch

Participants should start at one side of the pitch and run across the width at 70-80% of maximum pace. They should rest for 30 seconds on the other side and then repeat on the way back.

Bounding

Participants will run with high bounding steps from one side of the pitch to the other. They should use a high knee lift and land gently on the ball of their foot. They should use an exaggerated arm swing, opposite arm with opposite leg. They should rest for 30 seconds on the other side and then repeat on the way back.

Plant and cut running

Participants will end their warmup with a plant and cut drill. They will jog 4-5 steps, plant on the outside leg and cut to change direction. They will then accelerate and sprint 5-7 steps at high speed. They should then decelerate to a jog and do another plant. Continue this until they reach the other side of the pitch. They should rest there for 30 seconds and then complete the same exercise on the way back.

Figure 1. The FIFA 11+ Warm-Up Programme

APPENDIX 26: Kicking Assessment Cooldown Procedure

After the kicking test has been completed, participants performed a cool down to prevent stiffness and soreness after the kicking and strength assessments. This consisted of light aerobic exercise, followed by static stretches of the main lower limb (Figures 1-7).

Aerobic Exercise

The aim of this aspect of the cool down was to assist with a controlled reduction in heart rate and blood pressure, as well as regulation of blood flow. Participants were asked to perform light aerobic for 5 minutes.

Static stretches

Plank gastrocnemius stretch

Body position: Plank position with target leg knee extended.

Hold: 15 seconds.

Reps: 3 each leg.

Figure 1. Gastrocnemius stretch

Plank soleus stretch

Body position: Plank position with target leg knee flexed.

Hold: 15 seconds x3 each leg.

Reps: 3 each leg

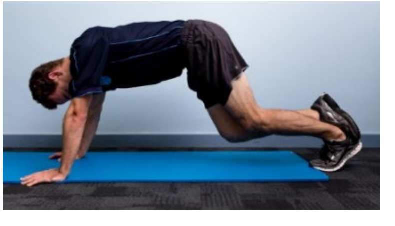


Figure 2. Soleus stretch

Kneeling hip flexor stretch

Body position: Half-kneeling position, pushing hip forward to feel stretch.

Hold: 15 seconds x3 each leg.

Reps: 3 each leg.

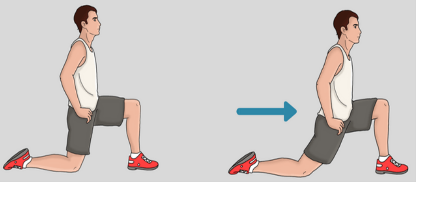


Figure 3. Hip flexor stretch

Kneeling hamstring stretch

Body position: Half-kneeling position, sitting back with front knee extended to feel stretch.

Hold: 15 seconds.

Reps: 3 each leg.

Figure 4. Hamstring stretch

Sitting adductor stretch

Body position: Sitting in lotus position with elbows on medial knees.

Hold: 15 seconds.

Reps: 3.

Figure 5. Adductor stretch

Side-lying quadriceps stretch

Body position: Side-lying, with top leg flexed and heel pulled to glute.

Hold: 15 seconds.

Reps: 3 each leg.

Figure 6. Quad stretch

Supine glute stretch

Body position: Supine with both knees bent to 90 degrees. Cross one leg over so that lateral heel is resting on the thigh of the other leg.

Hold: 15 seconds.

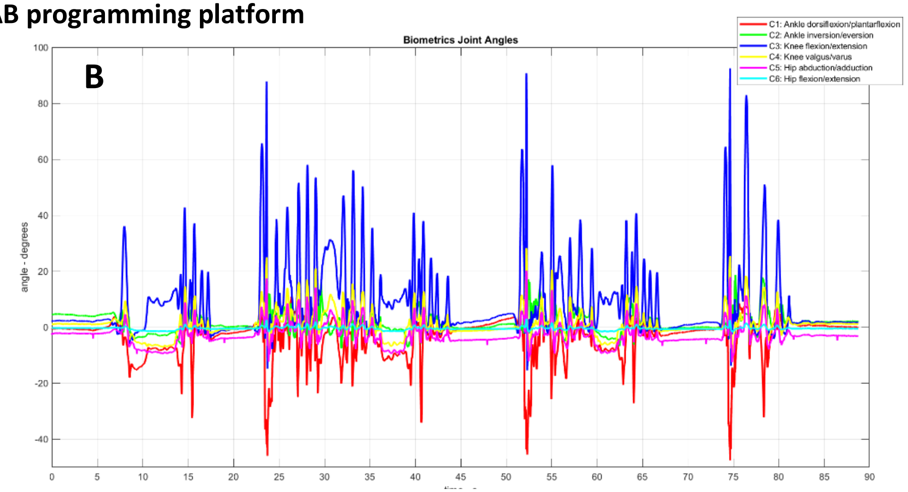
Reps: 3.

Figure 7. Glute stretch

APPENDIX 27: Electrogoniometer Data Graphs for Drop and Place Kicks

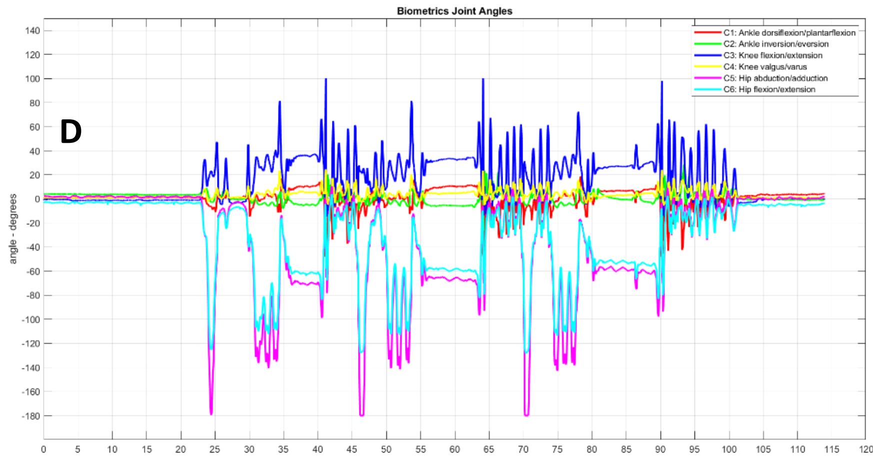
Electrogoniometer Data for Drop Kicks, presented graphically using MATLAB programming platform

A. Participant 1 – Drop Kick from the right

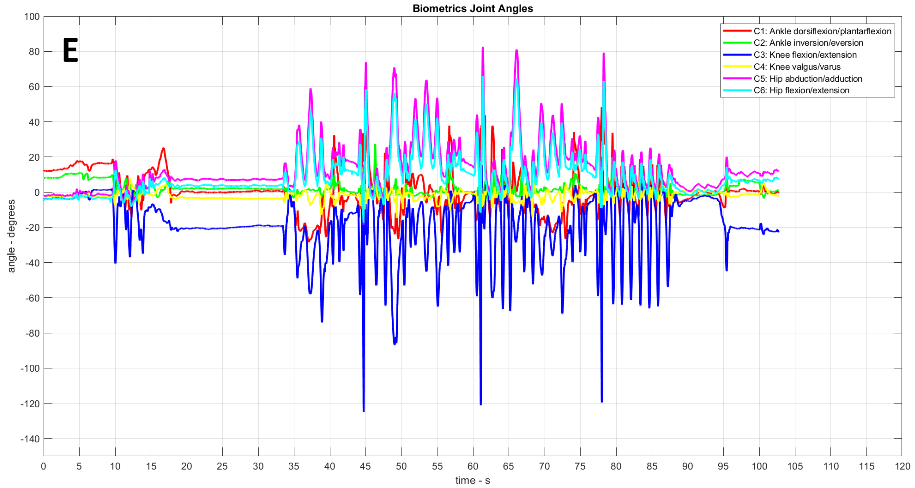


B. Participant 2 – Drop Kick from Centre

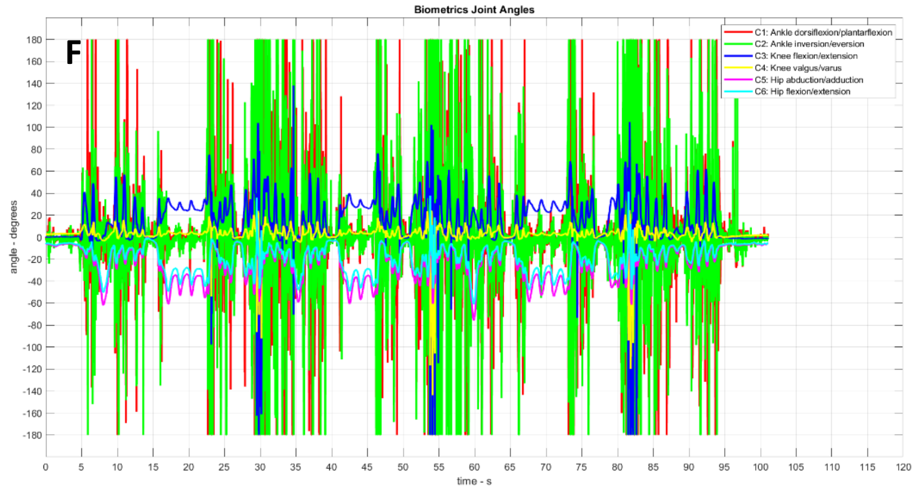
C. Participant 3 – Drop Kick from Centre



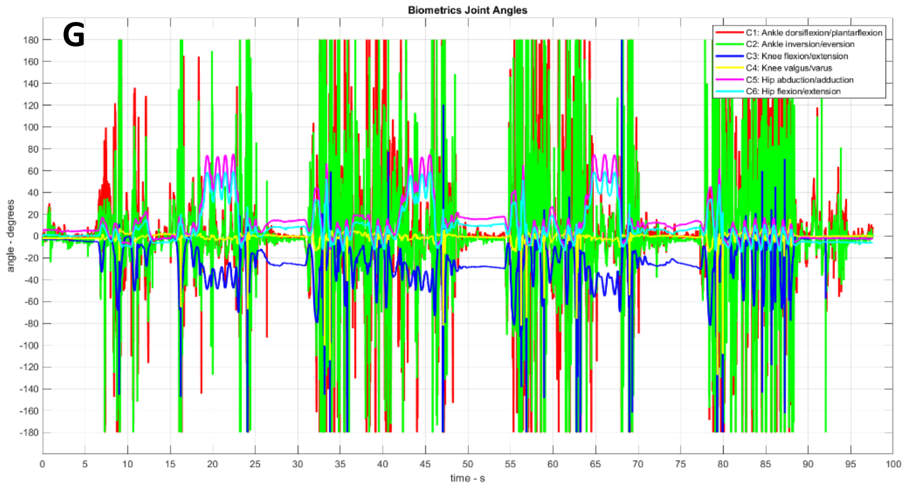
D. Participant 4 - Drop Kick from the Right



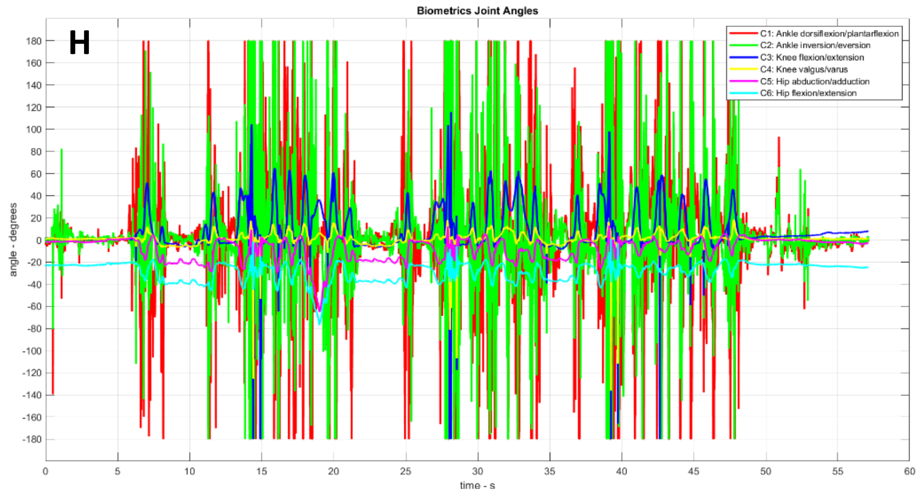
E. Participant 5 – Drop Kick from Right



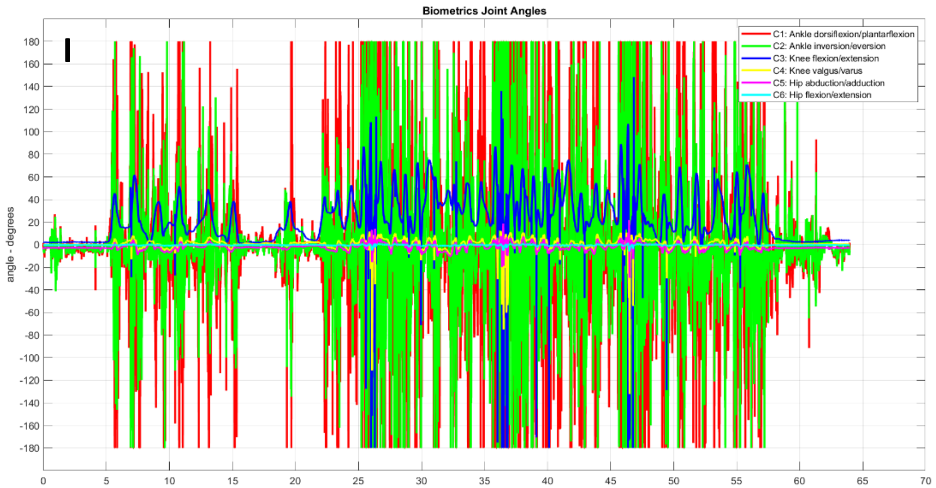
F. Participant 6 – Drop Kick from Centre



G. Participant 7 – Drop Kick from the Left

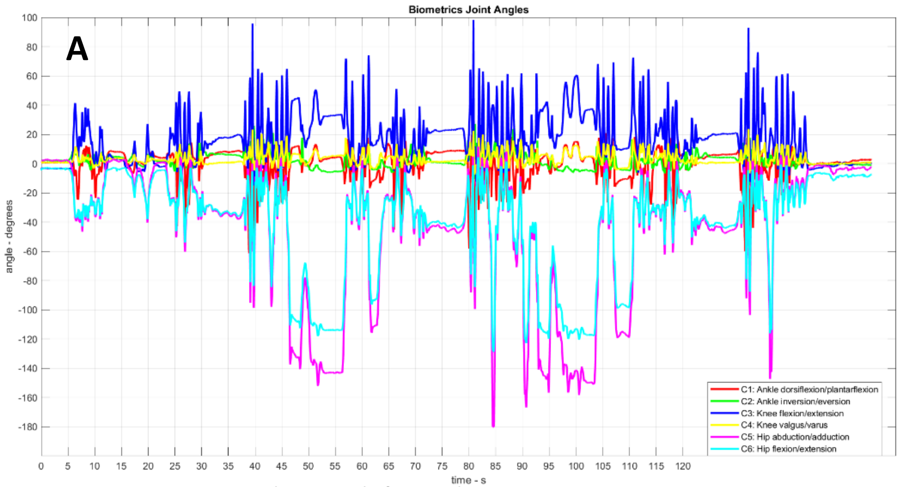


H. Participant 8 – Drop Kick Third Round

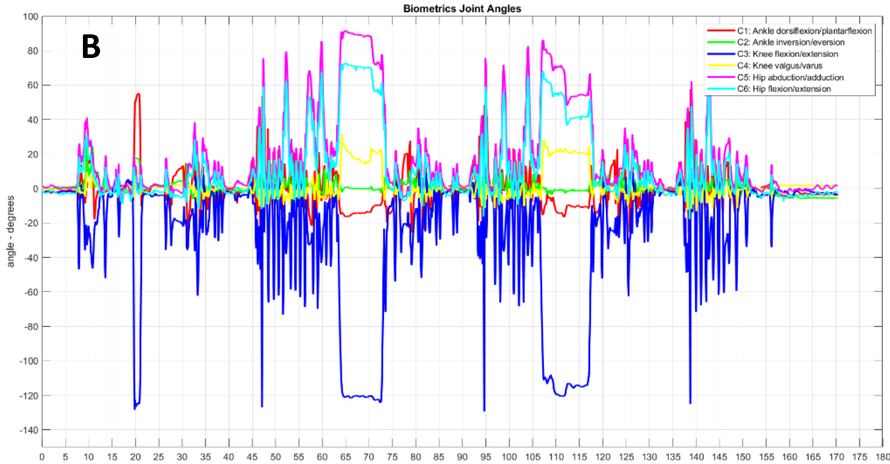


I. Participant 9 – Drop Kick from the Centre

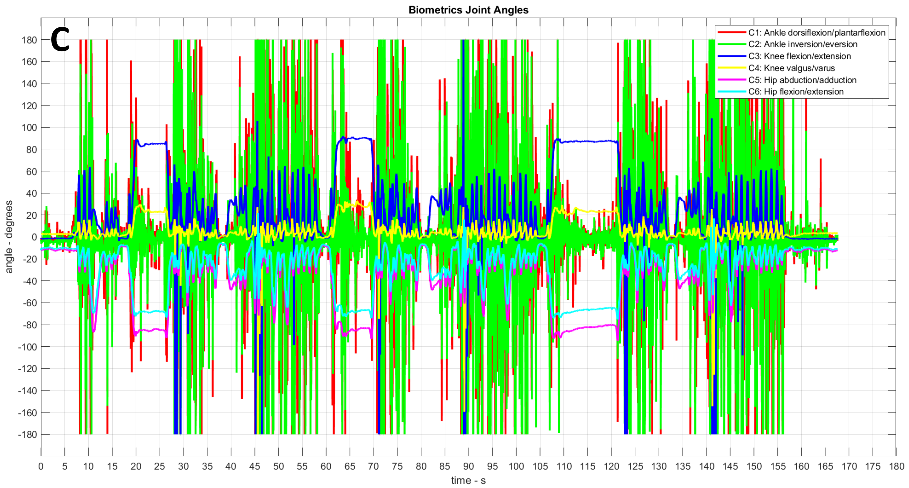
Electrogoniometer Data for Place Kicks, presented graphically using MATLAB programming software



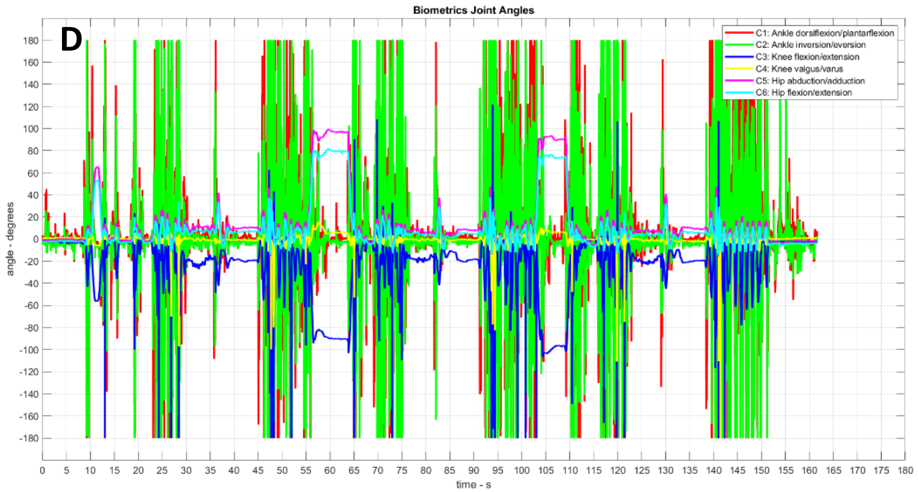
A. Participant 4 – Place Kick from the Centre



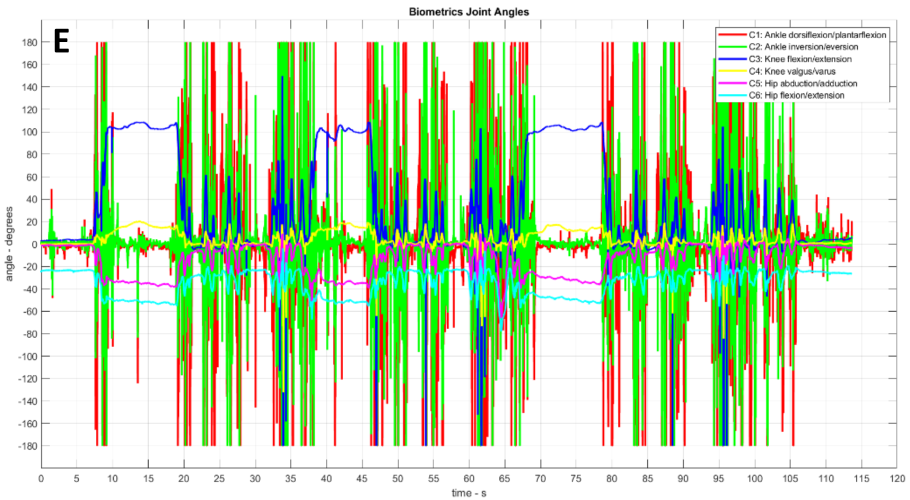
B. Participant 5 – Place Kick from the Centre



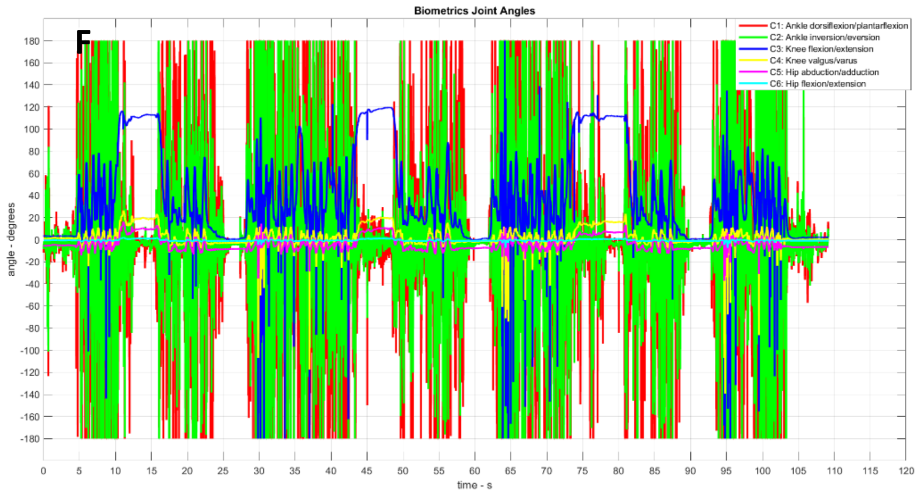
C. Participant 6 – Place Kick from the Centre



D. Participant 7 – Place Kick from the Centre



E. Participant 8 – Place Kick from the Centre



F. Participant 9 – Place Kick from Right

APPENDIX 28: Biometric Goniometer Joint Angle Results Tables

Biometric Goniometer Joint Angles for Drop Kicks – Unfiltered and *Filtered 20 Hz Butterworth Angles*

Player	Kicking Foot	Ankle (°)				Knee (°)				Hip (°)			
		Dorsi/Plantar Flexion		Inversion/Eversion		Flexion/Extension		Valgus/Varus		Flexion/Extension		Abduction/Adduction	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
P1	Right	10.69	-69.91	N/A	N/A	N/A	N/A	N/A	N/A	97.12	-4.92	37.10	-3.98
P1 (20 Hz filter)	Right	*10.06*	*-69.30*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*94.36*	*-2.82*	*35.08*	*-5.67*
P2	Right	6.95	-47.51	27.91	-5.56	90.91	-15.00	26.53	-10.24	12.52	-18.77	2.80	-1.72
P2 (20 Hz filter)	Right	*6.15*	*-43.18*	*26.61*	*-3.32*	*88.57*	*-11.08*	*25.89*	*-9.57*	*11.91*	*-18.17*	*2.69*	*-1.57*
P3	Right	9.93	-58.04	25.34	-7.22	92.26	-19.13	19.03	-11.66	90.54	-10.38	6.36	-75.11
P3 (20 Hz filter)	Right	*9.85*	*-56.39*	*24.00*	*-4.42*	*90.27*	*-15.57*	*18.55*	*-10.99*	*90.02*	*-9.94*	*5.61*	*-74.57*
P4	Right	12.33	-44.12	40.64	-13.68	93.69	-10.23	21.85	-4.88	87.45	-9.03	-7.27	-80.83
P4 (20 Hz filter)	Right	*12.07*	*-45.52*	*19.49*	*-8.49*	*91.77*	*-8.15*	*21.11*	*-3.47*	*86.97*	*-8.54*	*-7.31*	*-79.93*
P5	Left	13.08	-41.60	21.72	-17.33	119.32	-15.00	14.49	-8.53	82.53	-9.88	10.92	-64.86
P5 (20 Hz filter)	Left	*11.76*	*-40.59*	*19.57*	*-10.02*	*116.66*	*-11.33*	*13.28*	*-7.45*	*81.47*	*-9.53*	*9.55*	*-64.78*
P6	Right	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P6 (20 Hz filter)	Right	*163.39*	*-166.80*	*124.52*	*-122.78*	*96.76*	*-101.31*	*23.25*	*-88.56*	*59.58*	*-1.52*	*27.47*	*-44.44*
P7	Left	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

P7 (20 Hz filter)	Left	*158.77*	*-157.22*	*168.20*	*-141.25*	*94.24*	*-1.71*	*2.14*	*-75.76*	*56.05*	*-9.60*	*11.30*	*-43.11*
P8	Right	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P8 (20 Hz filter)	Right	*176.73*	*-154.82*	*147.64*	*-162.04*	*94.20*	*-83.60*	*15.61*	*-85.93*	*23.83*	*-8.92*	*-10.49*	*-40.36*
P9	Right	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P9 (20 Hz filter)	Right	*167.33*	*-165.48*	*170.19*	*-165.81*	*96.38*	*-88.05*	*10.06*	*-69.56*	*27.71*	*-9.09*	*0.82*	*-4.57*

Biometric Goniometer Joint Angles for Place Kicks – Unfiltered and *Filtered 20 Hz Butterworth Angles*

Player	Kicking Foot	Ankle (°)				Knee (°)				Hip (°)			
		Dorsi/Plantar Flexion		Inversion/Eversion		Flexion/Extension		Valgus/Varus		Flexion/Extension		Abduction/Adduction	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
P4	Right	18.18	-58.40	21.24	-15.50	97.71	-16.21	23.33	-7.30	104.98	-2.80	3.07	-88.59
P4 (20 Hz filter)	Right	*16.74*	*-56.85*	*19.75*	*-7.28*	*95.40*	*-11.68*	*22.62*	*-5.63*	*104.49*	*-2.16*	*2.50*	*-86.83*
P5	Left	26.50	44.94	12.39	-10.28	123.91	-10.38	10.39	-11.19	70.96	-12.63	14.79	-53.84
P5 (20 Hz filter)	Left	*26.07*	*39.72*	*9.09*	*-10.23*	*122.71*	*-8.72*	*10.14*	*-10.93*	*70.83*	*-12.53*	*14.65*	*-53.84*
P6	Right	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P6 (20 Hz filter)	Right	*174.06*	*-165.88*	*147.41*	*-146.77*	*96.51*	*-120.04*	*22.90*	*-93.72*	*65.41*	*-2.64*	*8.71*	*-51.77*

P7	Left	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P7 (20 Hz filter)	Left	*161.82*	*-169.75*	*162.36*	*-145.80*	*-0.65*	*-91.49*	*3.52*	*-64.41*	*46.24*	*-13.91*	*12.32*	*-37.56*
P8	Right	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P8 (20 Hz filter)	Right	*175.68*	*-173.58*	*163.30*	*-139.51*	*92.64*	*-103.00*	*15.27*	*-66.27*	*36.47*	*-6.24*	*11.55*	*-54.65*
P9	Right	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P9 (20 Hz filter)	Right	*173.68*	*-148.63*	*159.92*	*-161.96*	*92.23*	*-67.49*	*9.78*	*-68.37*	*29.45*	*-7.41*	*0.49*	*-4.76*

CHAPTER 8:

REFERENCES

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